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EUTROPHICATION OF SURFACE WATERS - LAKE TAHOE: INDIAN CREEK RESERVOIR

Lake Tahoe Area Council
South Lake Tahoe, California

May 1970

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EUTROPHICATION OF SURFACE WATERS— INDIAN CREEK RESERVOIR

First Progress Report
(FWQA Grant No. 16010 DNY)
May 1970

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Lake Tahoe Area Council
South Lake Tahoe
California

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FIRST PROGRESS REPORT

EUTROPHICATION OF SURFACE WATERS – LAKE TAHOE (INDIAN CREEK RESERVOIR)

by

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FEDERAL WATER QUALITY ADMINISTRATION
U. S. Department of the Interior
FWQA Grant No. 16010 DNY
Demonstration Project – Eutrophication
of Surface Waters
(Indian Creek Reservoir)

May 1970

Lake Tahoe Area Council
South Lake Tahoe, California 95705

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FWQA Review Notice

This report has been reviewed by the Federal Water Quality Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Quality Administration, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

PREFACE

This is the first of a proposed series of reports on the progress of FWQA Demonstration Grant No. 16010 DNY. The grant, made to the Lake Tahoe Area Council, has as its objective evaluation of the biostimulatory characteristics of impounded effluent from advanced waste water treatment processes presumed to reduce nutrients to safe levels in terms of eutrophication. The nature and scope of the report are set forth in Chapter I, as is the basic rationale on which the study is predicated. Subsequent chapters report and evaluate the progress of the study during the grant period December 1, 1968 to May 31, 1970.

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CHAPTER I

INTRODUCTION

ORIGIN OF INDIAN CREEK RESERVOIR

Indian Creek Reservoir is the terminus of a system designed to export, from the Lake Tahoe Basin, the final effluent from the waste water treatment facilities of the South Tahoe Public Utility District (STPUD). As described in Chapter II, the reservoir is an impoundment of highly treated waste water to be utilized for agriculture and such beneficial uses as may prove appropriate at the reservoir itself. Dilution of the impounded effluent is confined to surface runoff from snowmelt and occasional rains on a small drainage area. During the dry season when stored water is being released for agricultural use, the only input to the reservoir is reclaimed water from the STPUD. The factors which led to the creation of Indian Creek Reservoir are pertinent to an understanding of the needs and objectives of the study herein reported.

Although discharge of waste water effluents directly into Lake Tahoe has never been considered an acceptable alternative, the concept that they should be exported from the basin in the interest of preserving the unique quality of the lake developed during the decade of the sixties. Prior to that time disposal on land within the basin was generally considered adequate to overcome the public health and aesthetic objections to discharge into surface waters of the region. What changed public attitudes and engineering approaches was the recognition, in about the year 1960, that growing population pressure was leading to overfertilization of surface waters, with consequent algal blooms which interfered with normal beneficial use of water resources. Losses were identifiable in economic terms as well as in depreciated aesthetic and recreational values.

In the specific case of Lake Tahoe it was recognized that the clarity and beauty of the Lake was a consequence of an extremely low productivity resulting from its oligotrophic (nutrient poor) characteristics. Moreover, it was recognized that the Lake Tahoe Basin is a closed system subject to human imports of nutrients but only a quite limited export of nutrients by way of the Truckee River and some selective logging. It is obvious that the lake is the ultimate receiver of nutrients in the basin. However, in 1960 the problem of sewage disposal was the most critical question and major attention was directed to that problem.

Under a grant from the Max C. Fleischmann Foundation of Reno, Nevada, the Lake Tahoe Area Council conducted a comprehensive study of protection of the water resources of the Lake Tahoe Basin through management of wastes. The resulting report [1] recommended export of sewage effluents as one of three feasible alternatives. At about the same time (1961) the South Tahoe Public Utility District (STPUD) retained consulting engineers to develop a long-range permanent solution to its disposal problem. The idea of export as a practical solution, however, developed slowly. No area was willing to be the terminus of any waste export scheme. The problem of water rights entered in with such questions as: Under what authority may water be exported from the Basin? Whose water allocation is thereby reduced? What tradeoffs must ultimately be negotiated? Who benefits and who loses by waste water export?

As it turned out not all of these questions had to be answered prior to the creation of Indian Creek Reservoir. What did have to happen was an overcoming of the human attitude toward waste water: "If it isn't good enough for you, it isn't good enough for me." Two things had to be accomplished.

1. The water proposed for export had to be upgraded in quality until it met drinking water standards.
2. People had to come to understand that what constitutes acceptable high quality water almost anywhere else is not adequate to protect Lake Tahoe from eutrophication.

The first of these depended upon the development of new technology on a plant scale; the second, upon informing people of the reasons why drinking water standards are not adequate to protect Lake Tahoe. The first proved to be the most difficult. Its history is somewhat as follows.

Concern for eutrophication of surface waters, which emerged in the early 1960's, initiated a review of water criteria that has increasingly led in the direction of nutrient removal as an obligate objective of waste water treatment. To develop appropriate technology was an early goal of the Advanced Waste Water Treatment program of the U. S. Public Health Service. When the water quality program was transferred to the Department of the Interior, the FWQA continued the pursuit of this goal. Its most significant action in the Lake Tahoe situation was a series of Demonstration Grants to the STPUD for the development, on a plant scale, of processes for nutrient removal and for polishing of waste water so that it is indeed good enough for anyone, if not for discharge into Lake Tahoe. Export of effluent from such a plant soon became acceptable to people and the Indian Creek Reservoir site was selected for impounding reclaimed water logically destined for irrigation use.

Although the problem of sewage disposal was, as noted in a previous paragraph, the most urgent aspect of the threat of eutrophication of Lake Tahoe, export to Indian Creek Reservoir by the STPUD, and to other points by other agencies in the basin left unanswered a number of questions.

1. What percentage of the potential annual nutrient input to Lake Tahoe is removed from the Basin by export of sewage effluent?
2. What effect does human activity in the Basin have on the nutrient input to Lake Tahoe?
3. How effective is tertiary treatment of waste water in removing its potential to stimulate algal growth in Lake Tahoe water?
4. How effective is tertiary treatment of waste water in controlling algal growth in impoundments of effluents from such treatment?
5. What limnological developments in impounded tertiary effluents will affect beneficial uses of such impoundments?
6. What degree of treatment would be necessary to permit retention of reclaimed water in the Tahoe Basin without posing a threat to the quality of Lake Tahoe water?

Answering the first three of the foregoing questions is the objective of an FWPCA Demonstration Grant (No. 16010 DSW) to the Lake Tahoe Area Council. Progress toward such a goal is reported in three publications [2,3,4]. The last three questions underlie the need and objectives of the study herein reported.

NEED FOR STUDY

As implied in the preceding section, the need for the study is basically the need to determine whether advanced waste treatment at the upper limit of current technology is adequate to accomplish its purpose of reducing nutrients below the level at which they may accelerate the rate of eutrophication of surface waters in general, and of Lake Tahoe in particular. Associated with this need is the opportunity to trace the biological and ecological history of an impoundment of highly treated waste water created on previously vegetated dry land — an opportunity which in itself is so significant as essentially to represent a need. Only when such information is available may we determine the true utility of waters directly reclaimed from waste discharges, and in the case of Lake Tahoe evaluate the long term prospect of keeping reclaimed water in the basin as opposed to tradeoff with irrigation exports.

As noted in the previous section of this chapter, export of high quality reclaimed water from the Tahoe Basin was based upon the unique quality needs of Lake Tahoe, together with the tendency of people to consider water forever contaminated because it was once used to transport a small load of aesthetically unpleasant material. With time this attitude may be expected to give way to one more rational as more water is reclaimed and reused. However, the question of keeping the water in the basin will remain until it is shown that eutrophication of Lake Tahoe will not result from such action. In considering the need for study it is worth repeating again that water could meet U. S. Public Health Service Drinking Water Standards yet be totally unacceptable for discharge into Lake Tahoe. For example, a companion report to FWQA by the Lake Tahoe Area Council [4] shows profuse algal growth in Lake Tahoe water when 0.2 mg/ℓ of nitrogen was introduced, whereas the upper limit for drinking water is 45 mg/ℓ of nitrogen (as nitrate [16]).

Fortunately it is not necessary for water to be of a quality equal to that of Lake Tahoe in order for it to be acceptable for such beneficial uses as boating, fishing, and water contact sports. Thus the need for study of Indian Creek Reservoir in the broader general context of eutrophication of surface waters relates to the sequence of changes which reclaimed water may be expected to exhibit in reaching an ecological equilibrium, and to the water quality parameters which characterized such equilibrium.

OBJECTIVES OF STUDY

Pursuant to the needs, and in accord with the rationale, presented in preceding sections of this chapter the study was directed to four general objectives.

1. To determine the effects of reclaimed water from the STPUD Wastewater Reclamation Plant on biological, physical, and chemical parameters of Indian Creek Reservoir.
2. To relate these biological, physical, and chemical characteristics of the reservoir water to the nutrient concentrations and biostimulatory characteristics of the influent waste water.
3. To evaluate the relative contribution of biostimulants in the treated effluent and in the underlying soil and sediment exchange.
4. To correlate the results obtained in (1), (2), and (3) with results obtained in the laboratory and pilot pond studies of tertiary effluent in Lake Tahoe water.

NATURE AND SCOPE OF REPORT

The report herein presented is of the nature of a Progress Report covering the Grant Period December 1, 1968 to May 31, 1970. It constitutes, however, the Final Report for such period if the study is not continued under a proposed grant renewal (application under review, March 1970). Inasmuch as the study was conducted in cooperation with other agencies (see Organization For Study) the report draws upon the findings of others which are published separately or included in the Appendix. A companion grant to the Lake Tahoe Area Council (FWQA Demonstration Grant No. 16[illegible]DSW) [4] generated some of the data herein presented and evaluated. To minimize needless repetition of material and cost of report publication, all findings pertinent to Indian Creek Reservoir per se and to its stated objectives are herein reported. The companion report [4] deals with the effect of the tertiary effluent now exported to Indian Creek Reservoir on algal growth in Lake Tahoe water. A comparison of the reservoir and lake responses to the tertiary effluent is included in the report on Lake Tahoe [4].

As shown in the Table of Contents the report covers the geographical, geological, and hydrological character of the Indian Creek Reservoir area; the general limnological aspects of the reservoir; and the nature and findings of physical, chemical, and biological analyses of the reservoir water. The data presented were obtained principally during the period April 1969 to April 1970. Failure of the data period to extend over the stated grant period is the result of two factors: 1) the grant, although dated December 1, 1968 was made in February 1969, and 2) the unusual snowfall of the winter of 1968-1969 denied access to the reservoir until April 1969. This was to some degree compensated for by a mild winter in 1969-1970 which permitted a longer than normal period of sampling.

ORGANIZATION FOR STUDY

The study was made possible by Demonstration Grant No. 16010 DNY to the Lake Tahoe Area Council by the Federal Water Quality Administration of the U. S. Department of the Interior. Financial accountability for the project was maintained by the Council. Technical direction of the study was provided by the Lake Tahoe Area Council Board of Consultants (P. H. McGauhey, E. A. Pearson, and G. A. Rohlich) as a part of their commitment to Indian Creek Reservoir studies under the objectives of Grant No. 16010 DSW and as a donated public service. Pursuant to the objective of the DSW grant, data evaluation important to the Indian Creek Reservoir study were available from Dr. James B. Lackey, Consulting Biologist, Melrose, Florida; Dr. Arthur D. Hasler, University of Wisconsin; and Dr. E. J. Middlebrooks, University of California. Experimental work and data processing were under the direction of Dr. D. B. Porcella, Project Limnologist. Dr. Gordon L. Dugan, Project Biologist-Engineer assisted with field sampling. Mr. Peter Cowan, with the assistance of Mr. Jack Archambault and Mrs. Florence Kupka, was responsible for field sampling and guiding laboratory analyses. Agencies directly cooperating in the study included the California Department of Water Resources, which provided the geographical, hydrological, and geological data; the South Tahoe Public Utility District, which provided data on the amount and chemical nature of exported water, as well as a variety of services and counsel; and the FWQA Regional Office in Alameda, California, which made the study of benthic invertebrates utilized in the report. In addition, the FWQA contributed to the project through Mr. Thomas E. Maloney of the Pacific Northwest Water Laboratory, who served as Projects Officer; and Mr. William Johnson of the Alameda office, who served in a similar capacity at the regional level.

Laboratory facilities of the LTAC Demonstration Grant Laboratory at Tahoe City, made possible through the cooperation of the California Department of Fish and Game, were utilized for analytical and bioassay work.

ACKNOWLEDGMENTS

The Lake Tahoe Area Council, its Board of Consultants, and the staff of the Indian Creek Reservoir Project acknowledge with thanks the cooperation and assistance of the agencies and individuals who were helpful or instrumental in the progress of the study during the report period. Especial thanks are due to Mr. Willard Slater, Mr. Robert Nicklen and Mr. Neal Arnoldy, of the California Department of Water Resources, for providing environmental data on the Indian Creek Reservoir; to Mr. W. Arthur Noble, of the FWQA, for his study of the benthic organisms in the Reservoir; and to Mr. Russell L. Culp, Mr. David Evans and Mr. Jerry Wilson of the STPUD for analytical work and loan of equipment.

CHAPTER II

CHARACTERISTICS OF INDIAN CREEK RESERVOIR

GEOGRAPHICAL AND GENERAL CHARACTERISTICS OF AREA

Indian Creek Reservoir is located in Alpine County, California on the eastern side of the Sierra Nevada mountains. Its general relationship to Lake Tahoe, Luther Pass, and other geographical features of the area are shown in Figure 1, as is the profile of the 27-mile export line from South Lake Tahoe [5,6]. The reservoir was formed in 1968 by the construction of a main rockfill dam, 68 ft in height, on a tributary of Indian Creek in Diamond Valley. A smaller saddle dam of the same type was constructed to prevent overflow of the reservoir into a little used reservoir known as Stevens Lake. (See Figure 2.) The spillway crest at the main dam is at elevation 5600 ft. At that elevation the surface area of the reservoir is approximately 160 acres, or about 9 percent of the 1700 acres of drainage area above the dam. Downstream from the dam, Indian Creek flows northeasterly as a moderately recessed water course on which borders irrigable land. It has been estimated [5] that the total potential of the area to accept water either for supplemental irrigation or for full-service irrigation will exceed the outflow of Indian Creek Reservoir until about the year 2006. By that time the anticipated export from the South Lake Tahoe area will approach the estimated 13,928 acre-ft which agriculture in the immediate area can accept.

Figure 2 [5], which represents the maximum water surface of the reservoir superimposed on an aerial photograph of the reservoir site, shows that vegetation within the inundated area was originally largely scrub brush, except at the higher elevations. The darker spots within the reservoir area and to the east of the reservoir are principally piñon pine, the densest stand occurring on the ridges. The shaded areas in the figure are scrub brush, moderately dense. To the west of the reservoir, in the area adjacent to the saddle dam and Stevens Lake, there is a stand of pine timber intermingled with scrub brush. Cover on the drainage area generally varies from reasonably heavy brush to generally isolated stands of timber. Slopes are steepest on the west; on the order of 10 to 20 percent at the lakeside. To the east the slopes are about one-half of these values.

Soils at the reservoir site are shallow and rocky, overlying a hardpan which appears to be quite impervious. In preparing the reservoir site the vegetation was first removed and the soil stripped down to hardpan and rock to minimize the organic matter which might become a nutrient for organic growth in the overlying water.

CLIMATOLOGICAL AND HYDROLOGICAL CHARACTERISTICS OF THE AREA

The climate of the Indian Creek area is typical of that of the eastern or "rain shadow" side of the Sierras at altitudes in the 5000 to 6000-ft range. Average annual precipitation at the reservoir is reported [5] to be about 20 in., with 70 percent of this total occurring in the November through April season of the year. Although snowfall is substantial during the winter, rainfall accounts for much of the precipitation. Average monthly records from the U. S. Weather Bureau gage at Woodfords, California, some 3 miles northwest of Indian Creek Reservoir, show a variation from 0.34 in. in the months of July and August, when thunderstorms may be expected, to 4.28 in. in January, when prevailing storms occur.

Evaporation from free water surfaces in the area is, of course, greatest in the May through October period. At this time the daytime temperatures are highest, leading to a convective rise of air mass up the face of the adjacent Sierra Nevadas

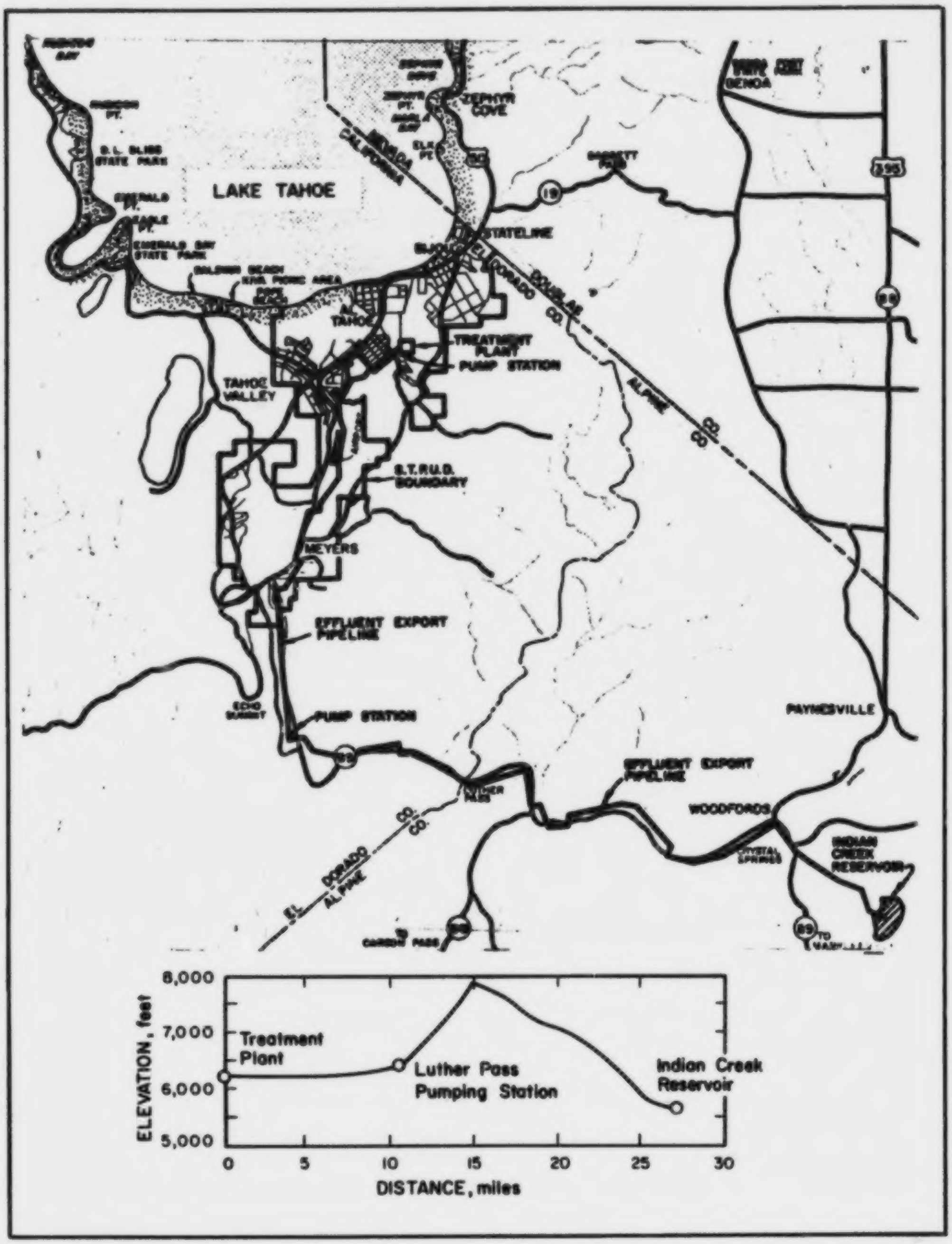
LAKE TAHOE
ZEPHYR COVE
ZEPHYR PT.
ELK PT.
D. L. BLISS STATE PARK
EMERALD PT.
EAGLE PT.
EMERALD BAY STATE PARK
BALDWIN BEACH
KIVA PICNIC AREA
NEVADA
CALIFORNIA
STATELINE
EL DORADO CO.
DOUGLAS CO.
ALPINE CO.
GENOA
19
50
395
88
TAHOE
TREATMENT PLANT
PUMP STATION
TAHOE VALLEY
S.T.P.U.D. BOUNDARY
MEYERS
EFFLUENT EXPORT PIPELINE
ECHO SUMMIT
PUMP STATION
89
LUTHER PASS
EL DORADO CO.
ALPINE CO.
EFFLUENT EXPORT PIPELINE
PAYNESVILLE
WOODFORDS
CRYSTAL SPRINGS
INDIAN CREEK RESERVOIR
CARSON PASS
88
89
ELEVATION, feet
8,000
7,000
6,000
5,000
Treatment Plant
Luther Pass Pumping Station
Indian Creek Reservoir
0
5
10
15
20
25
30
DISTANCE, miles

FIGURE I. GEOGRAPHICAL RELATIONSHIPS, INDIAN CREEK RESERVOIR AND EXPORT LINE FROM LAKE TAHOE BASIN (5,6)

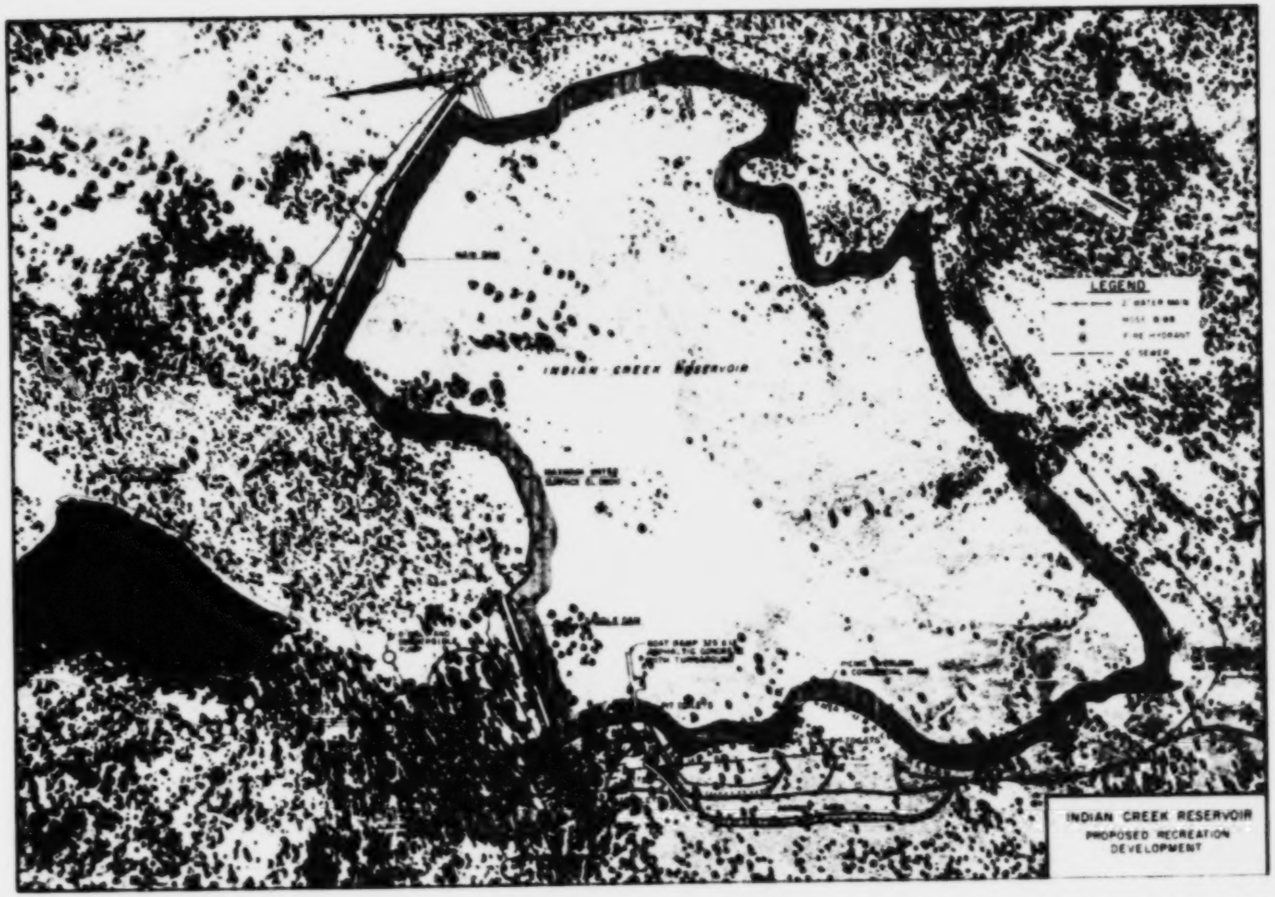
LEGEND
2" WATER MAIN
FIRE HYDRANT
6" SEWER
INDIAN CREEK RESERVOIR
INDIAN CREEK RESERVOIR
PROPOSED RECREATION
DEVELOPMENT

FIGURE 2. AERIAL PHOTO OF INDIAN CREEK RESERVOIR SITE WITH OVERLAY OF RESERVOIR AND PROPOSED IMPROVEMENTS (5)

Reproduced from best available copy.

which rise to elevations from 7800 to more than 9000 ft. Night time cooling of the air mass at higher elevations due to back radiation through the relatively thin atmospheric cover contributes to a subsidence of cool air at night, resulting in a day to night temperature change which may range from 25 to 40 degrees. Thus although the reservoir area is sheltered from prevailing winds, there is a considerable movement of air which scavenges the water surface of its overlying blanket of moist air and so encourages evaporation. Evaporative losses during the four warmest months may average some 24 in., 7 in. of which occurs in July. Figure 3 presents the evaporative losses in acre-ft of water to be expected during the warmer months from various surface areas which might pertain in Indian Creek Reservoir under any operational procedure.

Rapid rise of heated air up the face of mountains occasions thunderstorms. As in most mountain areas these tend to be intense, and because the soil in the Indian Creek Reservoir area is shallow and on appreciable slopes, some of the summer precipitation can be expected to run off into the reservoir. At time of more seasonal rainfall or of snowmelt on frozen ground, however, considerably more input of meterological water is to be expected. Inputs to the reservoir through the export pipeline of the South Tahoe Public Utility District are continuous year round. They are greatest during the summer season when the transient population of the Lake Tahoe Basin is greatest. Thus the effect of surface runoff on the nature of water reaching the reservoir is less in summer than would normally result from the climatological variation in the Indian Creek area.

Table I, prepared from data compiled by Clair A. Hill and Associates [5] for the South Tahoe Public Utility District, gives some dimensions to the annual variation and total yield to be expected from the drainage basin above Indian Creek Reservoir.

From Table I it may be computed that the expected maximum monthly runoff of surface waters to the reservoir is of the order of 49 times the minimum, whereas the input of reclaimed water varies by a factor of but 6.4 (589/92). Moreover, that the inflow ratio of reclaimed water to runoff may range from a low of 1 to 2.66 in January to a high value of about 118 to 1 in July, August, and September. The anticipated total input to the reservoir for the calendar year 1970 are of the order of 4.5 times as much reclaimed water as surface runoff. Because the operating schedule calls for withdrawing by irrigation and evaporation the entire reservoir input each year, it may be expected that the impounded reservoir water will resemble reclaimed water more closely as time goes on.

Table II, compiled from estimates by Clair A. Hill and Associates [5] indicates the increasing preponderance of reclaimed water during the period 1970 to 2018, assuming an average runoff of 815 acre-ft per year. Obviously this value is not invariable. Nevertheless, the percentages shown support the conclusion that the limnological behavior of Indian Creek Reservoir will be governed by the quality of reclaimed water; and that by study of the reservoir over a period of time the objective of evaluating reclamation processes, noted in Chapter I, should be achievable.

HYDROLOGY AND LIMNOLOGY OF INDIAN CREEK RESERVOIR

At its maximum water surface elevation of 5600 ft the volume of water impounded in Indian Creek Reservoir is 3130 acre-ft. Figure 4 shows the contour of the reservoir site. Data from this figure are translated into volume of impounded water and water surface area over the possible 60-ft variation of water depth and presented graphically in Figure 5. From Figure 5 and the values estimated for the year 1970 in Table I it may be computed that the expected variation in pool elevation at month's end should range from the minimum pool elevation of approximately 5582 ft (1000 a.f.) in October to about 5597 ft (2684 a.f.) in May, with a surface area variation of from 50 to 132 acres.

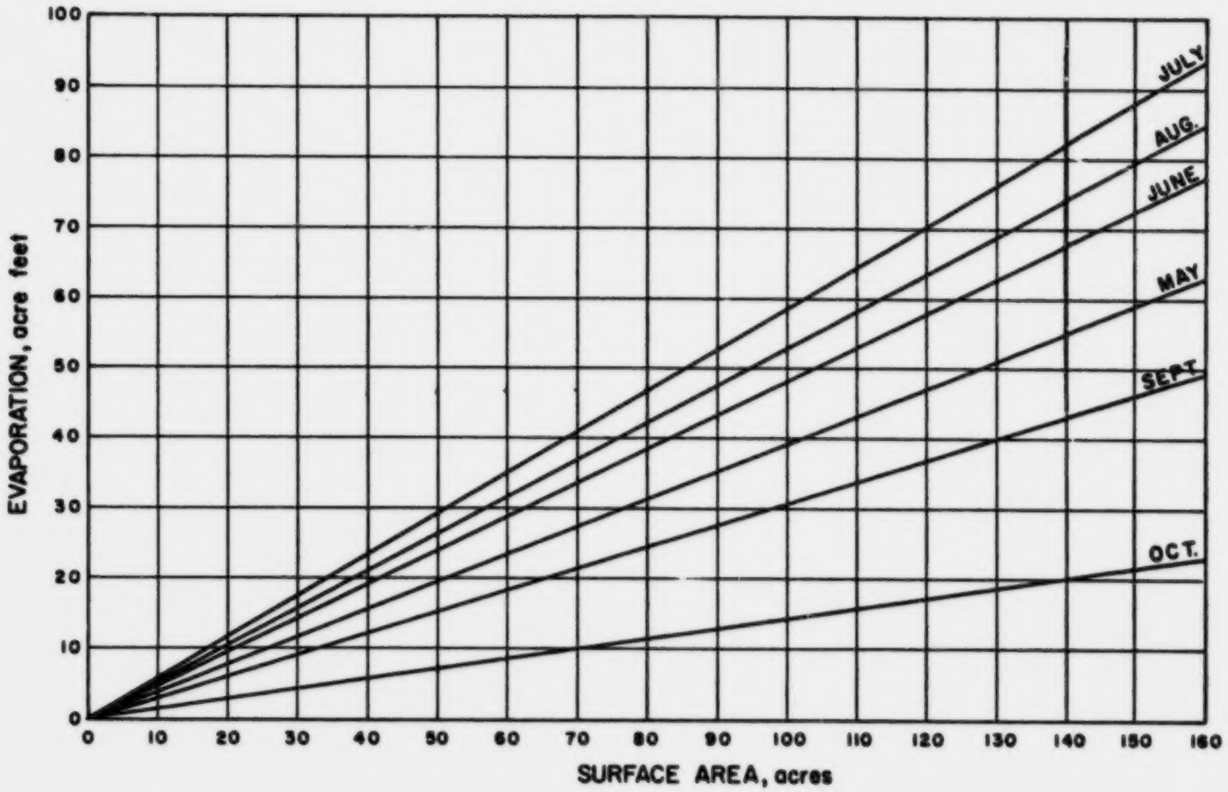

FIGURE 3. INDIAN CREEK RESERVOIR EVAPORATION BY MONTH IN ACRE FEET (5)

TABLE I

ESTIMATED WATER BUDGET, INDIAN CREEK RESERVOIR, 1970[a]

Month	Average Precipitation (in.)	Runoff (%)	Runoff to Reservoir from 1700 Acres (acre-ft)	Inflow Reclaimed Water (acre-ft)	Total Input to Reservoir (acre-ft)	Withdrawn for Irrigation (acre-ft)	Loss by Evaporation (acre-ft)	Impounded Volume at End of Month (acre-ft)
Jan	4.28	40	245	92	337	-	-	1,691
Feb	3.20	40	184	92	276	-	-	1,967
Mar	2.11	40	122	112	234	-	-	2,201
Apr	0.93	30	41	258	299	-	-	2,500
May	0.86	10	12	405	417	180	53	2,684
Jun	0.45	10	7	516	523	720	60	2,427
Jul	0.34	10	5	589	594	1,035	58	1,928
Aug	0.34	10	5	589	594	1,125	37	1,360
Sep	0.37	10	5	589	594	900	16	1,038
Oct	1.35	10	19	258	277	307	8	1,000
Nov	2.26	10	32	92	124	-	-	1,124
Dec	3.20	30	138	92	230	-	-	1,354
Totals for Year	19.69	-	815	3,684	4,999	4,269	232	-

[a] Estimated prior to construction of reservoir. See Table III, pg. 23 for observed operational values.

TABLE II

RECLAIMED WATER AS PERCENTAGE OF INPUT TO INDIAN CREEK RESERVOIR (ESTIMATED)

Year	Reclaimed Water Inflow (acre-ft)	Runoff Inflow From 1700 Acres (acre-ft)	Percent Reclaimed Water Annual (%)	Percent[a] Reclaimed Water Maximum 3-Months (%)
1970	3,684	815	72.0	99
1975	4,912	815	86.0	99.3
1980	6,140	815	88.0	99.5
1985	7,368	815	90.0	99.5
1990	8,596	815	91.5	99.5
1995	10,131	815	92.5	99.7
2000	11,666	815	93.5	99.7 +
2005	12,894	815	94.0	99.8 -
2010	13,815	815	94.0	99.8 -
2015	14,122	815	94.5	99.8 -
2018	14,276	815	94.5	99.8

[a] Computed from data [5] not shown in this table.

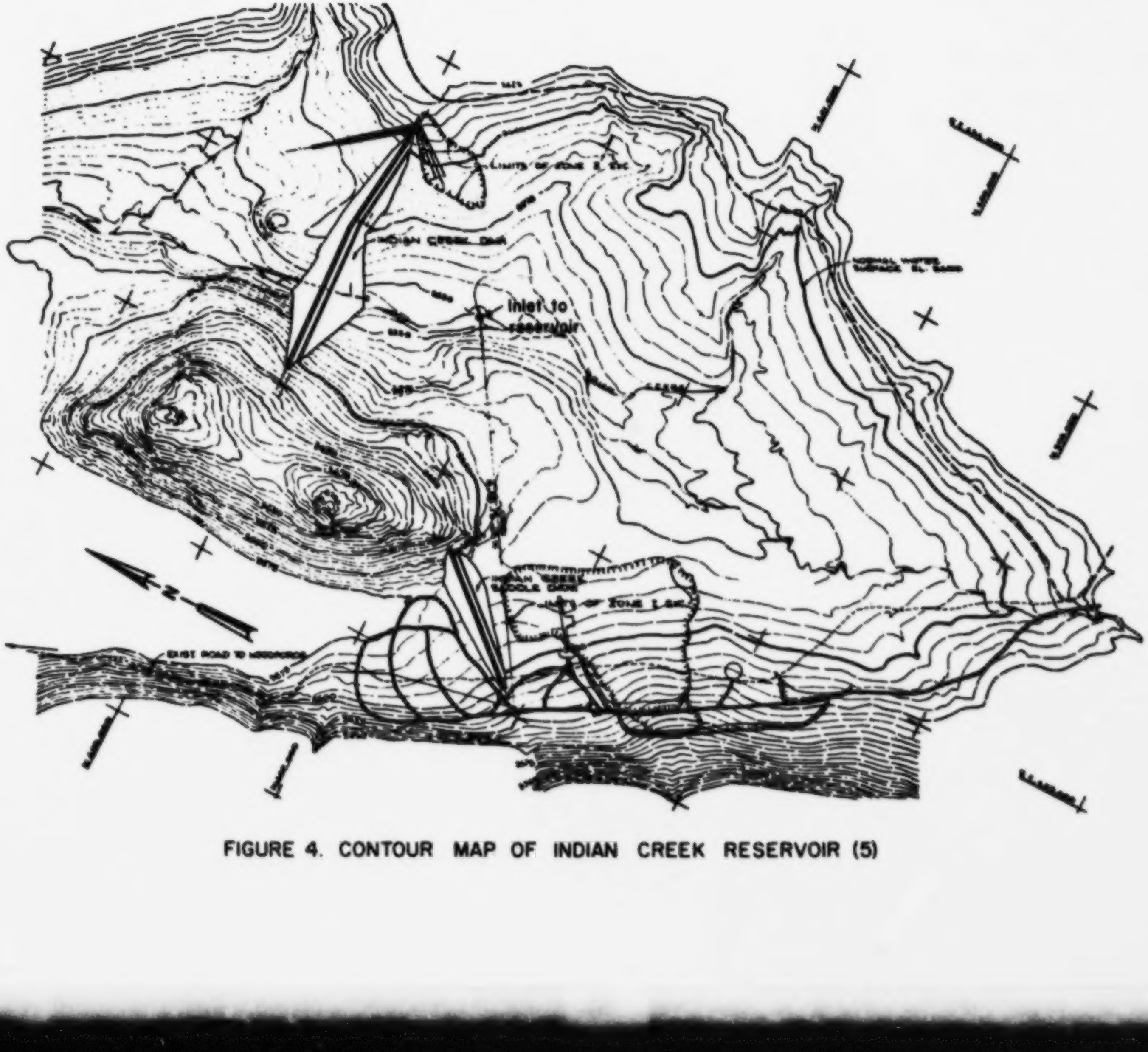
INDIAN CREEK DAM
LIMITS OF ZONE 2 EXC.
Inlet to reservoir
NORMAL WATER SURFACE EL.
INDIAN CREEK SADDLE DAM
LIMITS OF ZONE 2 EXC.
EXIST ROAD TO WOODFORDS
N

FIGURE 4. CONTOUR MAP OF INDIAN CREEK RESERVOIR (5)

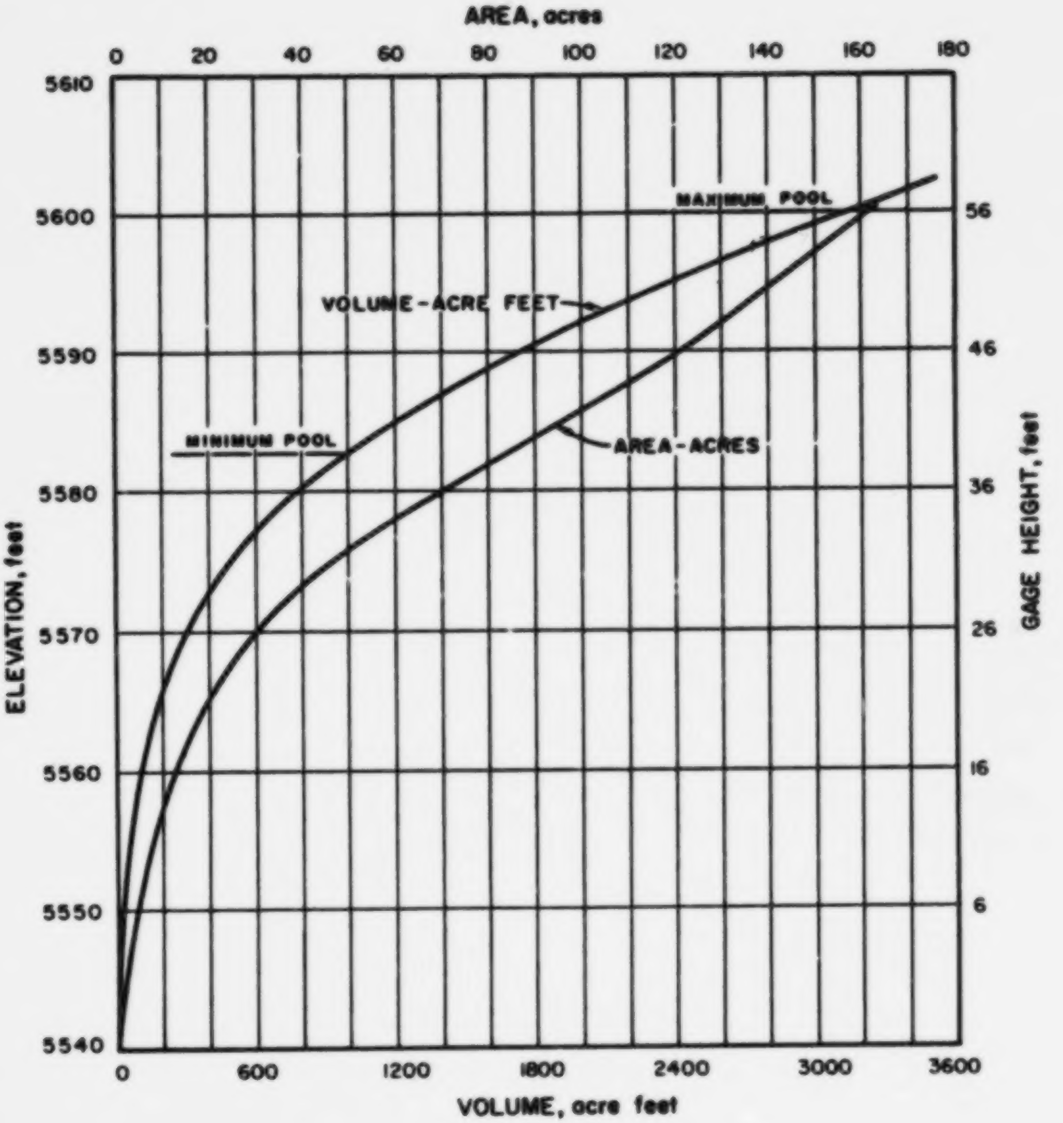

FIGURE 5. INDIAN CREEK RESERVOIR AREA AND CAPACITY (5)

Because the reservoir is newly formed it has no limnological history. To initiate such a record is the objective of the report herein presented; and of companion reports [7,8] of the California State Department of Water Resources and the Federal Water Quality Administration. Hydrologic and limnological observations made during the course of the study are presented and evaluated in subsequent chapters dealing specifically with results of laboratory and field analyses.

CHAPTER III

PROGRAM AND METHODOLOGY OF STUDY

PROJECT DESIGN

The scope and the nature of the program of sampling and analysis were designed to determine, within budgetary and climatological limitations, 1) the amount of nutrients going into the reservoir; 2) the effect of such nutrient concentrations on the level of productivity of the reservoir; and 3) the environmental fate of these nutrients. It was particularly desired to learn whether nutrients are sequestered in the reservoir sediments or biota, escape to the surrounding environment via the atmosphere, or pass through the reservoir with the outflowing water.

Sampling stations were chosen at the locations indicated in Figure 6. Initially, the influent to the reservoir (III) was sampled at the inlet to the reclaimed water outfall line at STPUD plant some 27 miles from Indian Creek Reservoir. Beginning in July 1969 this sampling point was moved to the Luther Pass Pumping Station, 10 miles closer to the reservoir. Discharge from the reservoir (B) was measured and sampled at the outlet gate. Here, water is released in significant quantities during the irrigation season and a small continuous outflow maintained at all times. A composite sample, designated as (C) in the data sheets (Appendix B) and made up of four 1-ℓ portions, was collected around Station 1. Analysis of this sample gave an estimate of the levels of nutrients in the reservoir. Since in a completely mixed reactor system the reactor and outflow concentrations are identical, an estimate of the degree of mixing in the reservoir was obtained by comparing the composition of samples (B) and (C).

As weather conditions permitted, weekly grab samples of the influent, discharge, and composite of the reservoir were collected in one-gal lots beginning in April 1969. At each sampling trip observations were made of reservoir depth, Secchi depth, air and water temperatures, and incident light to provide background information about the lake. The grab samples of water were collected at the appropriate stations and analyzed for the following chemical constituents: DO, COD, BOD, SS, VSS, the nitrogen species, orthophosphate, total P, Fe, Cl^-, Ca^{++}, alkalinity, pH, and conductivity. In addition batch type bioassays were performed on 100%, 10% and 1% concentrations of water sample in Lake Tahoe water.

Records of climate and of the flora and fauna observed in the Indian Creek Reservoir basin were also collected during the sampling trips to Indian Creek Reservoir. For example, wind direction and speed, cloud cover, and unusual climatological conditions were recorded regularly in a permanent log book. Also, visitations to the lake of deer and migratory waterfowl (principally, ducks and grebes) were observed and recorded. The location of developing vascular plant communities, floating algal material, and similar phenomena which would be expected to indicate changes in the reservoir conditions were noted. Data on the developing fish population were obtained, principally from the Department of Fish and Game.

In addition to this regular sampling program, samples of runoff were collected when runoff was observed. However, because of the dry environment, very little runoff occurred during the warm summer months. As a rule summer precipitation takes place in a relatively short interval of time and is rapidly absorbed or drained into the reservoir as runoff. This decreases the chances of personnel being on the site to obtain samples when runoff occurs.

Vertical and horizontal sampling over a 24-hr period was carried out in an attempt to define variations in the distribution of various components in the reservoir. These studies were performed at the different seasons of the year and

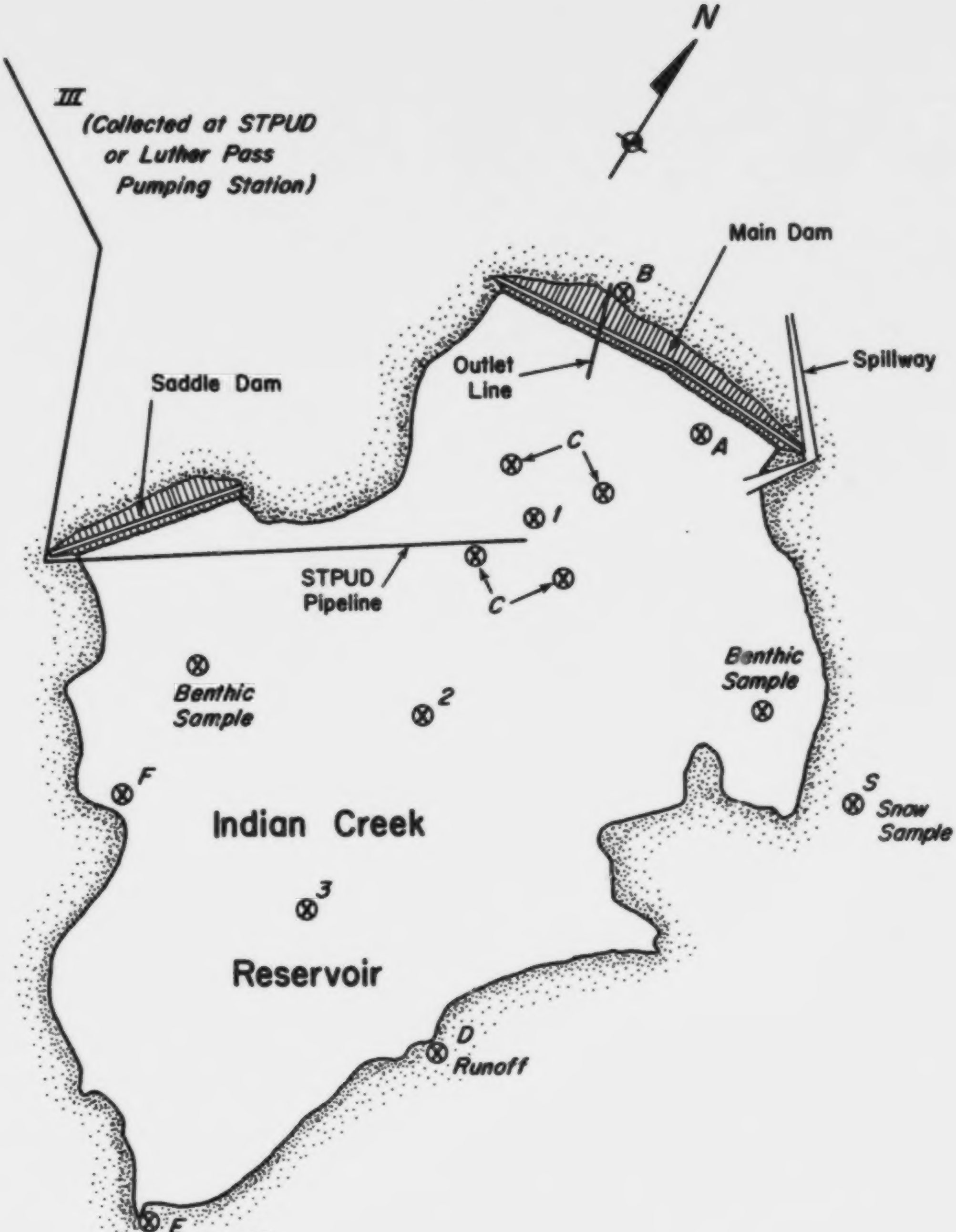
N
III (Collected at STPUD or Luther Pass Pumping Station)
Main Dam
B
Outlet Line
Spillway
Saddle Dam
C
A
1
STPUD Pipeline
C
Benthic Sample
Benthic Sample
2
F
S Snow Sample
Indian Creek
3
Reservoir
D Runoff
E Runoff

FIGURE 6. LOCATION OF SAMPLING STATIONS AT INDIAN CREEK RESERVOIR

at the permanent sampling stations. Measurements of DO, alkalinity, pH, and temperature were made. Also further chemical analyses were made to determine whether horizontal and vertical variation of nutrients occurred in the reservoir.

The bottom sediments, benthic invertebrates, phyto- and zoo-plankton were also sampled at appropriate intervals to study the community of Indian Creek Reservoir. A composite sample of the soil from 20 stations around the lake was collected in the zone above the water line from which vegetation had been stripped in preparing the site in order to get some idea of the probable organic content of the lake bed.

Data taken from studies performed by the Federal Water Quality Administration, Department of Water Resources, Department of Fish and Game, and the South Tahoe Public Utility District were also used in this report as necessary to complete the information needed to interpret the results.

METHODS AND MATERIALS

Various equipment was required to perform the sampling of Indian Creek Reservoir. A 12-ft aluminum boat and motor was used for most sampling trips out onto the lake. However, for difficult road conditions during periods of bad weather, it has been advantageous to use a one-man rubber boat to collect the composite sample. During the 24-hr sampling studies personnel camped overnight at the reservoir. A rented gasoline generator was used to provide electrical power for lighting and analytical equipment (pH meter, magnetic stirrer).

Temperatures were measured using a laboratory thermometer (-10° to 110°C). Light readings were taken with a Gossen Tri-Lux C light meter with a 20x translucent filter. The Secchi depth was determined as the average point of disappearance for an ascending and descending 8 in. diameter white, flat, circular, metal plate. Reservoir depth was read from a staff gage installed at the main dam.

The influent, discharge, and reservoir composite water samples were collected directly in polyethylene bottles used as sample containers. Samples at different depths below the water surface were collected with either an all plastic-latex rubber, Van Doren water sampler or a plastic Kemmerer sampler and transferred to polyethylene bottles. Bottom sediments were sampled by means of an Ekman dredge. Although rocks and sticks interfered with operation of the dredge in some shoreline areas, it was generally not too difficult to collect adequate lake sediment (as opposed to the soil stratum constituting the reservoir bottom). Usually a depth of 1-2 in. of silty-clay was collected at each sampling site. This was screened (U. S. No. 32) when collection and analysis of benthic invertebrates was the objective, or mixed and placed in a sample container for later chemical analysis. Phytoplankton samples were collected as water samples. Zooplankton were counted directly in water samples or collected by either surface tows or vertical tows (bottom of reservoir to surface) using a Wisconsin Style Plankton net (No. 20 mesh nylon) and bucket.

SAMPLE TREATMENT

Water samples were normally transported to the laboratory and stored overnight in a refrigerator ($< 5°C$) for chemical analysis the following day. When it was not possible to begin analysis on such a schedule, the water samples were filtered and the filtrate frozen for analysis at a later time. The analysis of DO and BOD was begun in the field (reagents added up to and including the concentrated H_2SO_4). Initially pH and alkalinity were determined in the field; however, no differences due to the time involved in transporting samples to the laboratory were observed and so all other analyses of the regular weekly water samples were performed in the laboratory. However, with the overnight sampling studies of the vertical and horizontal variations of chemical components during a 24-hr period, the measurement of DO, temperature, pH, and alkalinity were made as soon as possible after collection.

Samples were then composited for the different depths and stations and returned to the laboratory for further chemical analysis.

Phytoplankton were placed in brown glass jars and preserved in the field in a 5 percent Na_2CO_3 neutralized formalin solution. Zooplankton were preserved in 5-10 percent neutralized formalin in brown glass jars. The benthic invertebrates were placed in glass jars after having been screened and rinsed with reservoir water and 15 percent neutralized formalin was added for preservation. Bottom sediment samples were placed in brown glass jars and brought back to the laboratory for later analysis.

ANALYTICAL PROCEDURES

Preparation of Samples

Preliminary preparation of samples for physical and chemical analyses and bioassays varied somewhat depending on the specific method chosen for each assay. Water samples selected for flask bioassays, including Lake Tahoe water used for dilution, were filtered through Whatman glass fiber filters (GF/C) and finally through Millipore(R) filters (HA, 0.45 μ pore size). They were then stored in tightly stoppered polyethylene containers and frozen, unless the test was to begin within five days. For chemical analyses aliquots of the samples, both the unfiltered and those passed through the previously described glass fiber and Millipore(R) filters, were kept in tightly capped 2-ℓ polyethylene containers and stored in a refrigerator at temperatures approaching 0°C until all chemical determinations were completed. It was determined that no significant difference existed between chemical analyses of nutrients measured in unfiltered or filtered samples.

Chemical Assays

Chemical analyses of the filtered and unfiltered water samples were made according to Standard Methods [9] in determining biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, alkalinity, organic nitrogen, ammonia, chlorides, total phosphorus, calcium, and conductivity. Methods described by Strickland and Parsons [10] were considered more suitable for iron, nitrite, nitrate, and reactive inorganic phosphorus at the low concentrations prevailing in the Tahoe samples. Details of individual analyses are presented in Appendix G. All laboratory chemical determinations were subjected to replicate analyses on aliquots of the same sample as previously reported for the years 1967-1968 and 1968-1969 [2,3], to determine the precision of results attainable by the project staff by the analytical procedure used. The results showed that with the exception of organic nitrogen and total phosphorus in Lake Tahoe water, where concentrations are extremely small, the chemical analytical work is of good precision in terms of the coefficient of variation. A statistical analysis of the two methods of laboratory filtration (0.45 μ HA Millipore and GF/C Whatman glass fiber filter paper) indicated that there is no essential difference in the accuracy of the two methods.

Sediment chemical composition on a dry weight basis (available P, organic carbon, total N, and particle size) was determined according to methods described by Porcella, Kumagai, and Middlebrooks [11].

The technique for measuring total suspended solids (SS) and volatile suspended solids (VSS) was patterned from a combination of the procedures outlined in Standard Methods [9]; Strickland and Parsons [10]; and Maciolek [12]. Whatman glass filters (GF/C) were used in solids separation. The filters were prepared by soaking in distilled water to wash the fibers free of salts. They were then placed in a muffle furnace for 30 min at 450°C to destroy any organic matter present without fusing the glass fibers. After cooling, the filters were dried in a hot air oven at 75°C and tared quickly on a Mettler semimicro balance, to avoid error due to the hydroscopic nature of the dried filter. In making the solids determinations the sample was applied to the filter until the volume had passed through or until the filter was completely clogged. The volume of filtrate was noted. The filters with their load of suspended solids were dried overnight at 75°C and the dry weight recorded to the nearest 0.01 mg. They were then saved for further analyses by placing them in marked envelopes and storing in a refrigerator freezer. Samples in which the VSS value was desired were redried and reweighed to verify the suspended solids value. Thereafter the filters were ignited at 550°C for 2 hr, soaked with a few drops of distilled water to rehydrate the mineral matter, dried overnight at 75°C, and weighed. The difference between the SS weight and the weight after ignition was then used to determine the VSS in mg/ℓ.

In some cases it was necessary to revise the suggested methods in order to expand the scope of the analysis to encompass the wide range of nutrient concentrations encountered in the various samples assayed. The procedure was to prepare two standard curves for the Beckman Model B spectrophotometer, one using a 1-cm pathway cuvette and the other a 5-cm cuvette. The range of concentration for N, P, and Fe using the two pathway cells was from 1 μg/ℓ to 200 μg/ℓ. Samples in which the level of the constitutent exceeded the maximum range of concentration were diluted to the concentration range of the cells by a calibrated volume of deionized water.

Flask Bioassays

The theory and rationale of the flask assays are described in detail in the two previous progress reports [2,3]. The input (III), the output (B), the reservoir composite (C), and some selected samples (such as shoreline samples) were assayed at concentrations of 1% and 10% in Lake Tahoe water or at 100% (undiluted).

In making the assay of any nutrient source, the filtered sample was first diluted to the desired concentration with filtered Lake Tahoe water. One hundred and fifty mℓ of this solution was then placed in each of five sterile 250 mℓ Erlenmeyer flasks. Glassware used in assays was dry heat sterilized. Cells of a species of Selenastrum in good physiological condition were centrifuged and washed twice in Lake Tahoe water to minimize the chance of nutrient carry over from the stock culture to the test flasks. An equal volume of the suspended cells was then added to each test flask, so that the concentrations of cells in the 150 mℓ of liquid was approximately 50 cells/mm^3.

Loose fitting plastic beakers were inverted over the tops of the inoculated test flasks, prior to being placed in a 20°C constant temperature room and incubated on a gently moving (30 cycles/min) shaker table for a period of five days. Illumination of approximately 550 ft-c (5920 lux) intensity was provided by four 30 watt G. E. fluorescent lamps, No. F40-CW, Coolwhite, four ft in length.

The cell concentration in the test flasks were determined by cell counts at the end of 1, 3, and 5 days during the five week period of incubation. After the final counts were completed, suspended solids and pH measurements were made on a composite of the liquid in the five replicate flasks.

Test Organism

The alga Selenastrum gracile (Reinsch) was originally selected and utilized as a test organism for assays on the basis of consideration of characteristics of an ideal test organism and of favorable results reported by Skulberg [13] with the same genus. It has the disadvantage of producing large cells under rich nutrient conditions. In addition, newly formed cells tend to remain attached; but because they rarely exceed four in a group, cells are easily distinguished by "hand" counting with a microscope. These limitations were considered minor for the conditions prevailing at Tahoe when the hand procedure was used. However, in July 1969 a Model B "Coulter" counter was purchased to improve the efficiency and accuracy of cell counting. The Coulter counter functions on the principle that as each particle passes through an orifice, it displaces its own volume of diluent within the orifice and thus momentarily changes the resistance value between the electrodes positioned on each side of the orifice. A cell count is recorded each time the resistance is changed. Thus, the attached newly formed *S. gracile* cells would be counted as a single cell instead of the multiple number they represent. For this reason the closely related organism *Selenastrum capricornutum* which has the same approximate advantages as *S. gracile*, but do not remain attached after division, was substituted in studies in which the Coulter counter was used.

The basic cultures of the two *Selenastrum* species were maintained at a constant growth rate by the continuous culture method ($\theta = 5$ days) using a nutrient solution of 10 percent Skulberg's medium (Appendix B), which is specifically designed for culturing *Selenastrum*. The purity of the *Selenastrum* species was checked periodically by microscopic examination and contamination with other organisms was normally nonexistent. On one occasion this normal finding led to inadequate vigilance and a contamination of the basic culture with a "*Chlorella* type" organism developed between two successive microscopic checks. Consequently, the purity of the basic culture used in the assays for a period of approximately six weeks is in question. The results of the contaminated assays are discussed in later chapters.

Counting Procedures

As noted in the previous section (Test Organism) two basic methods were used to count the alga cells; the hand counting method up to July 1969 and the Coulter counter method thereafter.

The hand counting procedure was initiated by removing a 10 mℓ aliquot from each flask after an incubation time of one, three, and the final five days and centrifuging the aliquot for 10-15 min at 2000 rpm (approximately 800 times gravity). After centrifugation, 8-9 mℓ of the supernatant were removed with a Pasteur pipette and the pellet of cells resuspended in the remaining liquid medium. A drop of the suspension was then put on a Spencer Bright-Line hemocytometer for counting under the microscope. Duplicate counts were made for each flask and five replicates were performed for each concentration; thus a total of 30 counts were made for each concentration of sample tested. The duplicate counts for each flask were averaged, and the resulting values were then averaged to obtain a mean count for the five replicates constituting the assay.

The method used in the Coulter counter technique involved removing a 10 mℓ aliquot from each flask. The aliquot was then diluted with a saline solution so that the final concentration was from a maximum of 50 percent to the concentration that will provide a final count of less than 10,000 particles (counting capacity of the Coulter counter) for a 0.5 mℓ diluted sample. The maximum time required for each count is 13 sec. As was done in the hand count method a mean value was obtained for the five replicates.

Reliability, Sensitivity, and Precision of Cell Counting

Accurate cell counting techniques are imperative for meaningful kinetic studies of algal growth. A comparison of the results of the conventional hand counting technique versus the Coulter counter for the same samples is shown in Appendix G. The results of the hand counting technique, varies somewhat with the magnification used, but mainly with the ability of the individual doing the counting to judge representative cell concentration areas, superimposed cells, attached cells, etc. The Coulter counter, however, when in proper operating order, records each time a particle passes between the two electrodes. A coincidence correction coefficient is multiplied by the number of particles recorded by the Coulter counter, thereby, providing a statistical correction for the possibility of superimposed cells passing between the electrodes at the same time. Thus it is obvious that the Coulter counter should provide a much higher degree of sensitivity and reliability as well as the added benefit of a considerable time saving over the hand counting technique. The reliability of the Coulter counter was emphasized when the same sample was introduced to the Coulter counter several times in succession and the difference in the numerical results were found to be insignificant ($<$ 1 percent coefficient of variation).

Computer Analysis of Data

The computer was utilized to analyze the data more efficiently, especially to obtain values of maximum growth rate, $\hat{\mu}$; log maximum growth rate, $\hat{\mu}_\ell$; mean maximum cell concentration at the end of the growth period, $\hat{X}$; nutrient concentration at one-half the maximum specific growth rate, K_s; yield coefficient, Y; and the decay rate, K_d.

Statistical Comparisons

The computer was also utilized to determine the mean, coefficient of variation, range of 95 percent confidence levels, and correlation factors. These determinations and their significance are discussed in chapters which follow.

CHAPTER IV

RESULTS OF STUDY

INTRODUCTION

Pursuant to the objectives noted in Chapter I and in line with the program outlined in Chapter II, physical, chemical, and biological observations were made of the progressive changes in the water budget and in water quality in Indian Creek Reservoir. The results of these observations are hereinafter presented and discussed; and further evaluated in Chapter V. Data were collected by members of the project staff and by the California Department of Water Resources during specific studies of the reservoir; and by the South Tahoe Public Utility District and the U. S. Weather Bureau as a part of their normal operating procedures. Estimates by Clair A. Hill and Associates for the STPUD [5] were also used in computing the water budget of the reservoir during the period November 1968 through March 1970, herein reported.

PHYSICAL OBSERVATIONS

Water Budget of ICR

Filling of Indian Creek Reservoir was begun on March 31, 1968. Table III summarizes the input of reclaimed water and withdrawals from the reservoir as reported monthly by the STPUD during the period April 1968 to March 1970, together with observations from other sources which permit some preliminary observations concerning the water budget of the reservoir. Columns 1 through 4 of the table represent data taken directly from STPUD monthly reports and converted to acre-ft units. Some discrepancy appears in Column 4 between STPUD data on withdrawals and preliminary values observed by the Department of Water Resources. This is in part due to the fact that the values shown for STPUD data include both withdrawals for irrigation and smaller amounts discharged from the export line prior to its outfall in Indian Creek Reservoir for use by road contractors in roadbed sprinkling, etc. The difference, however, remains appreciable although for the purpose here intended it is largely immaterial.

Column 5 represents the volume of water in acre-ft which would have been in the reservoir at the end of each month were there no inflow from surface runoff, nor loss of water through evaporation to the atmosphere and infiltration into the soil underlying the reservoir. In Column 6 are reported actual reservoir volume estimates based on depth gage readings (spillway crest at depth gage reading of 56 ft) converted to acre-ft by use of Figure 5, (Chapter II). The value of 280 acre-ft shown in Column 6 for the end of October 1968 was computed from observation by the STPUD [14] that the volume of water actually in Indian Creek Reservoir increased by 622 million gal during the period October 1968 to July 1, 1969. Direct observation of the reservoir showed it to contain some 2300 acre-ft at the end of June 1969. Therefore it must have contained 280 acre-ft in October 1968. Of the 622 million gal, 525 were exported from STPUD, leaving a total of 97 million gal which can be attributed to surface flow after evaporative losses and infiltrative losses have been subtracted. Inasmuch as the April to October 1968 period spans the driest months of the year, the difference between 352 (Column 5) and 280 acre-ft (Column 6) might represent the minimum possible loss of water from the reservoir via evaporation and infiltration, if no rainfall whatsoever occurred. These values can be estimated with some accuracy from rainfall and other weather data as later described in relation to Table IV and Table V.

TABLE III

SUMMARY OF RECLAIMED WATER INPUTS TO INDIAN CREEK RESERVOIR
(April 1968 – March 1970)
(STPUD Monthly Reports)

1	2			3		4	5	6
Year and Month	Daily Flow to Indian Creek Reservoir (mgd)			Total Inflow For Month		Withdrawn for Irrigation Plus Pipeline Outlet (acre-ft)	Cumulative Total (Input Minus Withdrawn) (acre-ft)	Total in Indian Creek Reservoir Observed or Computed (acre-ft)
	Maximum	Minimum	Average	(mgd)	(acre-ft)			
1968								
Apr	2.4	0.9	1.84	55.1	179	0	179	
May	2.4	1.9	1.96	60.77	197	0	376	
Jun	3.1	0.0	2.4	66.9	218	0	594	
Jul	3.3	1.8	2.7	82.8	269	302	561	
Aug	2.7	1.9	2.5	76.7	250	369	442	
Sep	3.6	0.0	1.7	51.6	168	414	196	
Oct	1.8	1.1	1.6	48.0	156	0	352	280[a]
Nov	2.2	0.2	1.52	37.9	123	0	475	
Dec	2.5	0.8	1.6	49.8	163	0	638	
1969								
Jan	4.1	1.1	2.2	69.0	225	0	863	
Feb	2.5	1.4	1.9	53.9	175	0	1038	
Mar	3.8	1.6	1.9	57.5	187	0	1225	
Apr	3.3	2.2	2.6	76.8	250	0	1475	2280[a]
May	3.0	1.0	2.1	63.9	208	0	1683	2200[b]
Jun	3.8	2.0	2.67	81.0	264	0	1947	2300[b]
Jul	2.8	2.2	2.5	75.9	247	0	2194	2350[a]
Aug	3.0	1.9	2.7	82.3	268	319 (260[b])	2143	2150[b]
Sep	2.6	1.8	2.1	61.9	202	203 (177[c])	2142	2100[b]
Oct	2.0	1.5	1.8	56.4	184	0	2326	2150[a,b]
Nov	2.04	1.07	1.67	50.18	163	0	2489	2100[b]
Dec	3.37	1.28	2.06	63.93	208	0	2697	2300[b]
1970								
Jan	5.40	1.74	2.80	86.97	283	0	2980	
Feb	3.16	2.10	2.34	65.52	216	0	3196 (3130[d])	
Mar	3.01	1.87	2.31	58.19[e]	189	0	3385 (3130[d])	3100[b]

[a] STPUD data.

[b] LTAC data.

[c] DWR preliminary data.

[d] Capacity of reservoir.

[e] A portion of the total inflow 71.71 mgd was diverted prior to entering the reservoir.

From Table III it is noteworthy, although to be expected, that during the winter of 1968-1969 the volume of water impounded in the reservoir increased rapidly in comparison with the reclaimed water input. For example, by the end of April 1969 the actual volume of water was some 2280 acre-ft as compared to the 1475 acre-ft pumped to the reservoir. The difference, 805 acre-ft, therefore represents the accumulation due to surface runoff after all infiltrative and evaporative losses have been charged to runoff. Subsequently, during the summer of 1969 when another dry period occurred the volume of water discharged (some 522 acre-ft) is a rough estimate of the input to the reservoir during August and September from sources other than reclaimed water, again subject to increase to account for evaporation and infiltration.

In order to give better values to the foregoing observations, and to estimate the evaporation and infiltration from the reservoir, Tables IV and V were developed.

Table IV sets up a water budget estimate from Indian Creek Reservoir based on monthly data from the U. S. Weather Bureau, values from Table III, direct observations, and appropriate computations as noted hereinafter:

Column 1: Self-explanatory.

Column 2: Data from the U. S. Weather Bureau Station at Woodfords, California, approximately three miles from Indian Creek Reservoir. Totals shown are based on the assumption that 10 in. of snow = 1 in. of water.

Column 3: Runoff factors as per Chapter II, Clair A. Hill and Associates Report to STPUD [5].

Column 4: From field observations by Demonstration Grant staff and STPUD.

Column 5: Interpolated from Figure 5, Chapter II [5].

Column 6: Computed from data in Columns 2 and 3, and drainage area of 1700 acres minus water surface area, Column 5.

Column 7: From STPUD records summarized in Table III.

Column 8: Interpolated from Figure 3, Chapter II [5] for months of May through October. Values for April and November assumed greater than zero because both months were relatively dry in 1969, hence more than normally subject to evaporative losses.

Column 9: Computed from data in Columns 2 and 5.

Column 10: Columns (6 + 7 + 9 - 8) = summation of inputs and outputs with the exception of infiltrative losses.

Column 11: Computed as the theoretical volume in reservoir if no infiltration occurs. Represents the observed volume in the reservoir (Column 12) at the end of the preceding month, plus the input for the current month (Column 11).

Column 12: Interpolated from Figure 5, Chapter II, utilizing observed values of reservoir water depth shown in Column 4.

Column 13: Column 11 - Column 12.

Column 14: Column 13 divided by days in month, Column 1.

Column 15: Computed from values in Column 14 divided by inundated area in acres, Column 5.

The values for infiltration rate calculated in Table IV show some appreciable variability from month to month, with an erratic tendency at the time when water is being discharged from the reservoir for irrigation. This variability is not surprising, however, because the strategy for obtaining the values shown unavoidably includes

TABLE IV

WATER BUDGET, INDIAN CREEK RESERVOIR

1	2				3	4	5	6	7	8	9	10[a]	11[a]	12	13	14	15
Year and Month	Precipitation				Runoff Factor	Observed Water Depth in Indian Creek Reservoir (ft)	Water Surface Area (acres)	Runoff From Drainage Area (acre-ft)	Reclaimed Water Inflow (acre-ft)	Evap. Loss From Surface (acre-ft)	Precip. on Water Surface (acre-ft)	Net Change in Water Budget Uncorrected (acre-ft)	Calc. in Total Reservoir (acre-ft)	Observed Volume in Reservoir (acre-ft)	Est. Infil. Loss (Col. 11-12) (acre-ft)	Calculated Infiltration Loss (acre-ft/day on area Col. 5)	Calc. Infil. Rate (ft/day)
	Rain (in.)	Snow (in.)	Total (in.)	Total (ft)													
1968																	
Oct					.10	17.2	14	19[b]	156	2.5		172		280			
Nov	3.09	-	3.09	.258	.10				123			154					
Dec	3.40	-	3.40	2.83	.30				163								
1969																	
Jan	12.83	30.0	15.83	1.32	.40												
Feb	4.82	64.4	11.26	.937	.40												
Mar	1.51	17.0	3.21	.267	.40												
Apr	1.43	-	1.43	.119	.30	50.5	142	+ 56	+ 250	- 20[c]	+ 17	+ 303		2280			
May	0.05	-	0.05	.004	.10	49.75	137	+ 1	+ 208	- 53	-	+ 156	2436	2200	236	7.6	.054
Jun	2.06	-	2.06	.172	.10	50.5	137	+ 27	+ 264	- 66	+ 23	+ 248	2448	2300	148	4.9	.035
Jul	0.19	-	0.19	.016	.10	51	140	+ 2	+ 247	- 82	+ 1	+ 168	2468	2350	118	3.8	.028
Aug	-	-	-	-	.10	49.54	154	0	+ 268	- 72	-	+ 196	2546	2150 260[d]	136	4.4	.033
Sep	0.25	-	0.25	.028	.10	49.2 +	133	+ 4.4	+ 202	- 40	+ 4	+ 170	2320	2142 177[d]	0	0	0
Oct	1.93	-	1.93	.161	.10	48.75	130	+ 25	+ 184	- 19	+ 21	+ 211	2353	2150	203	6.5	.050
Nov	0.74	-	0.74	.062	.10	49.2	133	+ 9.7	+ 163	- 10[c]	+ 8.3	+ 171	2321	2100	221	7.37	.055
Dec	6.14	6.00	6.74	.570	.30	50.8	138	+ 268	+ 208	-	+ 79	+ 555	2655	2300	355	11.5	.083
1970																	
Jan	9.80	3.70	10.17	.847	.40	54.1	153	+ 524	+ 283	-	+ 129	+ 957	3257	2850	407	12.5	.082
Feb	1.64	7.30	2.37	.198	.40	54.6	154	+ 120	+ 216	- 10[c]	+ 31	+ 357	3207	2900	307	11.0	.071
Mar	0.92	11.50	2.07	.173	.40	55.1	158	+ 108	+ 181[e]	- 15[c]	+ 27	+ 301	3201	3100	101	3.26	.021
Total[f]	25.17	28.5	28.02	2.335													

[a] Uncorrected for infiltrative loss.

[b] Based on average year.

[c] Assumed at typical rate.

[d] Withdrawn.

[e] Thirty-nine acre-ft of total reclaimed water (220 acre-ft) was diverted and did not enter reservoir.

[f] April 1, 1969 to March 10, 1970.

in the infiltration values all of the errors of assumption existing in the "Runoff Factor" and the time-area-evaporation relationships of Figure 5. The values shown, however, are typical of tight soils after a few months of continuous inundation. They therefore give rise to a considerable degree of confidence in the assumptions used.

Table V is a refinement of the estimate of infiltration rate at Indian Creek Reservoir based on depth observations by the LTAC project staff reported hereinafter in Table VI. The months of June and July are analyzed in Table V. During these months there were no releases for irrigation; runoff factors are low; and evaporation, although appreciable, is subject to more accurate estimation than during months of variable daytime temperatures. The months of June and July are analyzed separately for evaluation of the rate of infiltration into the reservoir bed to seek evidence of replicability of results. The overall infiltration rate for the entire two-month period is also calculated. As noted in the table, values of 0.0385, 0.0318, and 0.0332 ft/day were computed for June, July, and the two-month period, respectively. These values are similar to some of those appearing in Table IV, based on monthly totals. Although the lack of observed data on runoff and evaporation introduces some error in the estimates of infiltration rate, the evidence is strong that the loss of water from the reservoir via infiltration amounts to around 0.035 ± ft of water/day. Such a value is within the range which might be expected [15] in tight soils inundated continuously for more than a year.

An attempt was made to compute the infiltration rate during the month of August when no rainfall occurred. The results, however, were negative because the data are not in sufficient detail to describe the behavior of the reservoir during periods of water release. From this failure, and the zero infiltration reported in Table IV for September 1969 when the daily release rate was some four times the inflow rate, it is evident that there is some problem of relating depth gage readings to volumes in the reservoir at times when the equilibrium of the water surface is uncertain.

Residence Time

The parameter variously known as residence time, flowing through time, or detention period cannot be evaluated for Indian Creek Reservoir on the basis of existing limnological information on the impoundment. The data presented in Tables III and IV show that the input to the reservoir is predominantly reclaimed water exported from the Lake Tahoe Basin. However, in December 1969 the input by runoff and direct precipitation on the reservoir surface is estimated to exceed the 208 acre-ft of reclaimed water by some 139 acre-ft. During the summer months when releases of water occur a great deal of short circuiting of influent must occur because of the close proximity of the reclaimed water inlet to the reservoir and the outlet facilities (see Figure 6, Chapter III). This physical limitation of the Indian Creek Reservoir, it may be concluded, is certain to complicate any attempt to evaluate the water quality and eutrophication characteristics of the reservoir.

Physical and Environmental Parameters of Indian Creek Reservoir

Weekly observations of several physical parameters of Indian Creek Reservoir are summarized in Table VI. Results of similar 24-hr observations appear in Table XIV (Appendix B). There are presented such values as clarity (Secchi), air and water temperatures, and light intensity in greater detail, showing variations throughout the day and with depth below the water surface. Such detailed data are of particular importance in evaluating the quality of water in the reservoir and its relationship to the biological changes observed, as discussed in subsequent sections of this chapter. In the context of the physical characteristics of the reservoir, however. Table VI is adequate to reveal the magnitude and variation in the water and air temperatures, and in the clarity of the water as measured by the Secchi disc.

TABLE V

ESTIMATE OF INFILTRATIVE LOSSES FROM INDIAN CREEK RESERVOIR, JUNE AND JULY 1969

Date	Observed Water Depth in Indian Creek Reservoir (ft)	Volume Water Impounded (acre-ft)	Input Reclaimed Water for Period (acre-ft)	Reservoir Area (acres)	Input Surface Runoff (acre-ft)	Input Rainfall on Indian Creek Reservoir (acre-ft)	Loss by Evap. (acre-ft)
5/29/69	49.75	2200	-	135	-	-	-
7/1/69	50.50	2330	+ 279[a]	140	+ 26.9	+ 23.5	- 65

Calculations

Runoff from 0.172 ft rainfall in June @ factor = 0.10

.172 x .10 (1700 - 137.5) = 26.9 acre-ft

Rainfall on reservoir surface @ 137.5 acres

.172 x 137.5 = 23.6 acre-ft

Evaporative loss from Figure 5, Chapter II, = 65 acre-ft/month

Observed increase in volume = 2330 - 2200 = 130 acre-ft

Calculated increase in volume (no infiltration loss)

(279 + 26.9 + 23.6 - 65) = 264 acre-ft

Loss by infiltration = (264 - 130) = 164 acre-ft/31 days/137.5 acres

Rate of infiltration = $\frac{164}{31 \times 137.5} = \underline{.0385}$ ft/day (June only)

7/29/69	50.85	2393	255	141	1	2	- 74

Rate of infiltration (July only) = $\frac{121}{27 \times 141} = \underline{\underline{.0318}}$

Rate of infiltration for period 5/29/69 to 7/29/69 (calculated by procedure above)

$= \frac{266}{58 \times 138} = \underline{\underline{.0332}}$

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[a] From STPUD daily operating records.

TABLE VI

WEEKLY OBSERVATIONS OF ENVIRONMENTAL DATA, INDIAN CREEK RESERVOIR
(MAY 1969 - MARCH 1970)

1	2	3	4	5	6	7	8
Date	Time of Day (hours)	Secchi Depth (meters)*	Water Depth (ft)	Water Temp. (°C)°	Air Temp. (°C)	Light Intensity (ft-c)	Remarks
May 1969 29	-	1.68	49.75	17	-	-	-
Jun 4	-	1.17	49.8	18	-	-	-
19	-	0.91	50.1	18	-	-	-
26	-	2.18	50.4	18	-	-	-
Jul 1	-	2.05	50.5	18	-	-	-
10	-	1.47	-	19	-	-	-
17	1140	2.22	50.7	22	-	6600	Clear, sunshine, slight westerly breeze, 2"-4" chop, water slightly turbid
22	1430	1.81	50.7	25.1	29.4	-	Cloudy, thunderstorm in distance, septic odor detected near reservoir outlet
29	0945	3.12	50.85	22.2	22.5	4300	Very clear, few small clouds, southerly wind strong at times
Aug 5	1330	2.68	50.85	20.8	25.1	9400	Clear skies, northerly wind
12	0930	1.70	50.35	20.5	25	4600	Skies crystal clear, water surface like glass
19	1030	1.75	50.25	20	21.7	5200	Clear skies, winds northwesterly
Sep 2	1530	2.59	49.54	21	31	4600	Cloudy, wind constant from southwest, water surface choppy
10	1545	1.95	49.5	20.5	29.5	4600	Clear, few small clouds, wind calm to breeze from west, water surface glassy to rippled
15	1245	1.22	49.0	19	22.6	5800	Strong west winds 15-20 mph, 20-30 mph at 1545 hr, waves 6"-10"
25	1245	1.40	48.2	17	25	5500	Clear, slight winds from northwest, ripples on water surface
Oct 2	1430	1.12	49.2	16	20.5	3200	Thin clouds, wind northerly, water near dam appeared extremely dark
8	1400	-	48.7	14	-	2200	Storm clouds, northerly winds 30-40 mph, waves 18" amplitude
16	1520	1.27	48.6	9.5	12	4000	Patchy clouds, winds southwesterly strong at times, water rough but no whitecaps
24	1030	1.30	48.7	9	15.5	1340	Cumulus cloud, overcast, slight breeze from southwest, water surface calm
30	1015	2.15	48.75	8	11.5	4400	Clear, sunny, no waves
Nov 13	1150	2.30	48.85	8.5	16	4200	Clear and sunny, water calm
19	1125	2.50	49.0	9.5	11	3000	Clear skies, thin clouds, slight northwest breeze, water surface ripples
26	1125	3.04	49.1	[illegible]	9	4450	Clear skies, light clouds
Dec 3	1055	3.40	49.2	4	11	4300	Clear, thin clouds, water surface like glass
16	1100	2.64	49.5	3	11	4000	(Dec 15 no wind) Dec 16 southwest wind too strong for sampling all stations, wave amplitude 2-3 ft
Jan 1970 5	1410	2.90	50.2	4	-0.5	2800	Clear blue skies, slight southwest breeze, lake frozen over except small area to west, ice 3" at sampling station
Feb 5	1515	1.81	54.1	4.2	10	2000	Cloudy, overcast, wind slight southwest
18	1510	1.85	54.6	4	5	5400	Sky blue to partly cloudy, clouds large dark, wind slight and northerly
Mar 3	1211	0.99	54.75	3	8	6400	Bright sunny, southwesterly winds strong, wave amplitude 8-10"
18	1200	0.80	55.5	6.8	4.2	6400	Clear and bright, few clouds, light breeze, waves 2-3"
26	1145	0.94	55.2	8.2	12	5300	Clear to partly cloudy, slight northerly wind, waves 2-3"

*NOTE: Subsequently in April and May 1970 readings increased to 4.3-5.8 m.

°At one ft below water surface.

Clarity of Water. During the period June 1969 through March 1970 the clarity of the water in Indian Creek Reservoir varied from 0.84 to 3.46* meters. Except for a high degree of clarity for a short period — around the first of August — the greatest sustained clarity of the reservoir water occurred in the November to January season. During that period the water temperatures were low and not conducive to growth of aquatic organisms, although the light intensity during the middle hours of the day were not greatly reduced from those reported earlier in the year. Lowest values of clarity (Column 3) occurred in February and March. Although no rigorous experimental data exist to document the causes of this reduction in clarity, Table IV shows that the greatest surface runoff occurred in December 1969. This might be expected to bring in appreciable suspended solids from surface wash. Further, the freezing of the water surface in January could have caused an oxygen deficit in the water. To protect rainbow trout planted in Indian Creek Reservoir in August 1969, the STPUD installed a fine bubble aeration-turnover system (Hinde, "Air Aqua") in the reservoir. Such a mixing device normally stirs up a body of water and therefore might be expected to inhibit sedimentation and to resuspend sediments previously deposited on the bottom. In general, the clarity of the reservoir was typical of shallow impoundments of good quality water.

Temperature. From Table VI it is evident that the water temperature followed the air temperature in a normal manner, with less response than the ambient air to transient climatological phenomena. Of greatest significance to the water quality and biological productivity of the reservoir is the fact that the near-surface water temperature maintained levels in the 18-22°C range over essentially a four-month range. Data presented in Table XIX (Appendix B) show that only a 4°C temperature drop occurred in the top 14 meters of water during July. In September there was no difference between the surface and the 14-m level, the surface having cooled down to the 18°C range which had prevailed during previous warm months.

Environmental Factors. Although no daily observations are available at Indian Creek Reservoir to identify the environmental factors of climate some general findings may be drawn from Column 8 of Table VI. As might be inferred from the precipitation data in Table IV clear weather prevailed at Indian Creek Reservoir during the period herein reported. Wind direction seems to be heavily influenced by the adjacent mountain range, with northerly and southwesterly winds predominating. Waves in the 18-in. to 3-ft range were observed during weekly sampling. Southwesterly wind in October and December and northerly winds in March accounted for the roughest water observed.

Wind movement across Indian Creek Reservoir and the extent to which it disturbs the water, has a particularly important bearing on the degree to which the reservoir is mixed. As shown in Figure 6 (Chapter III) the inlet and outlet to the reservoir are so positioned that only limited mixing could result during periods of discharge. Mixing of the reservoir therefore depends upon several other factors; all of which are significant:

1. Flow from the inlet to the shallow south end, and other reaches of the impoundment as the reservoir is filling.

2. Flow from shallow to deep end as release rate exceeds flow rate during seasonal releases of water.

3. Gravity and thermal gradients resulting from heavy inflow of water from drainage area, e.g., rain and snowmelt in December 1969.

4. Wave action and seiches induced by winds.

From Figure 4 (Chapter II) it may be seen that a southerly wind roughly parallels the long axis of the reservoir, moving from the shallowest water towards the dam. Waves induced by such wind action then tend to stir up sediments in the shallows and, if of any duration, to pile up water at the deepest end of the reservoir. The subsequent movement of water is therefore from the inlet of reclaimed water to the shallow southern end of the pool. This same movement is induced by a northerly wind which in turn may develop a seiche that results in a return flow to the dam when calm is restored. Southwesterly winds blow toward the lake shore northeast of the dam (see Figure 4) and, because of the protection of the high ridge at the west abutment of the dam, can be expected to initiate a counterclockwise movement of surface water in the reservoir that should have a mixing effect, at least in the deeper portion of the lake north of an east-west line passing through the saddle dam.

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*5.8 in May 1970.

Conclusions

Concerning the physical characteristics of Indian Creek Reservoir it is herein concluded that:

1. Estimates of runoff and evaporation rates previously reported [5] appear to be sufficiently valid to permit a reasonable water budget for Indian Creek Reservoir.
2. Year round observations designed to establish more accurate runoff and evaporation rates should be made.
3. Infiltration rates as of mid-1969 were of the order of 0.035 ± ft of water per day, a value which is both reasonable and plausible.
4. The clarity of Indian Creek Reservoir water during the period of observation was typical of shallow impoundments of relatively good quality water.
5. Water temperatures in the upper stratum of the reservoir, where light and other environmental factors are most favorable to plankton growth, reach an 18-22°C range also favorable to biological activity.
6. With only minor exceptions, the observed data on physical characteristics of the reservoir are in line with typical and explainable phenomena, although not in sufficient detail to permit statistical evaluations.
7. The importance of wind movement in describing and evaluating the limnology of Indian Creek Reservoir is such that more detailed and continuous observation of wind direction and intensity should be a part of any continued surveillance of the reservoir.

CHEMICAL OBSERVATIONS

Daily observations of the chemical and bacteriological quality of reclaimed water exported to Indian Creek Reservoir by the South Tahoe Public Utility District were compiled by the District from the beginning of export on March 31, 1968 and reported on a monthly basis thereafter. Analyses of the impounded water were begun by the LTAC Laboratory on October 3, 1968, prior to the beginning of the FWQA Indian Creek Reservoir Demonstration Grant, as a part of ongoing studies of eutrophication of surface waters likewise supported by the FWQA (see Chapter I). Beginning in April 1969, analysis of the exported reclaimed water was made also by the LTAC Laboratory as a part of its weekly and monthly sampling program at Indian Creek Reservoir. Analysis of surface and ground waters in the vicinity of the reservoir have been reported by the California Department of Water Resources [7]. Results of these various analyses are summarized in Appendix A, B, and C. In regard to Appendix A it should be noted that some analyses were made essentially on a daily basis, whereas others were made weekly. Consequently, the minimum, maximum, and average values reported for the several parameters are of different degrees of reliability. Likewise some of the Department of Water Resources data (Appendix C) extend over a period of years - others are fragmentary.

Comparison of Indian Creek Reservoir and Other Waters

Leaving for subsequent sections of the report a detailed evaluation of the observed changes in water quality in Indian Creek Reservoir and of their significance in terms of eutrophication of surface waters, Table VII is presented to give some idea of the comparative quality of Indian Creek Reservoir and other waters of the area.

Columns 2 and 3 of the table are derived from weekly sampling of reclaimed water (L-III) and Indian Creek Reservoir (C) during the period June 4 through August 12, 1969 at which time no releases of water were made from the reservoir. However, as reported in Table VI, the reservoir depth was 49.8 ft at the beginning of the period and increased to only 50.95 by August 12. Thus it must be expected that the quality of water in the reservoir was dependent upon both that of the input water and of the water already impounded. The latter was influenced by runoff and precipitation during the previous winter; and any progressive changes which may have occurred during the period of observation due to aquatic growth or other phenomena are obscured by averaging of weekly observations. Data for the West and East Forks of the Carson River (Columns 4 and 5) are maximum and minimum values observed in bimonthly sampling during the 1968-1969 water year. Data in Columns 6 and 7 with the exception of DO for Indian Creek represent a single analysis in June of 1968 and indicate by their identity that Stevens Lake was the source of Indian Creek on that occasion. Data on the domestic well (Column 8) are several years old. Current Ward Creek and Lake Tahoe data are included for a frame of reference.

Because the data are not all of the same time reference nor of equal duration no profound conclusions are to be drawn from Table VII. However, it may be noted that in general the reservoir was of better quality than the influent reclaimed water. Both exceeded surface runoff in nitrogen but were less in phosphorus than any but Ward Creek and Lake Tahoe. Moreover Indian Creek had about the same total nitrogen as Ward Creek, which likewise flows from a relatively uninhabited area. In the amounts of calcium, chlorides, iron, alkalinity, and conductivity the reclaimed and Indian Creek Reservoir water reflect their previous history of usage, although both are high quality waters when compared with Public Health Service Drinking Water Standards [16]. (Note that nitrogen and phosphorus in the table are expressed in micrograms per liter, hence the apparent largest number in the table – 16,700 in Column 2 – is about 17 mg/ℓ.)

More extensive data on Indian Creek Reservoir are hereinafter analyzed in relation to water quality. These include yearly averages and extremes which do not necessarily check the shorter-term averages used in Table VII.

A small amount of water escaped from the Indian Creek Reservoir at all times, apparently due to leakage around the outlet pipe or through its valve system. As noted in Table XXI , Appendix C, this was estimated by the California Department of Water Resources (DWR) at 0.01 cu ft/sec during the months of August and September 1969. More frequent visual observations by members of the LTAC staff placed the discharge at about twice this amount. Continuity of discharge, however, is more important than the exact rate in assessing the quality of water in the system.

Samples of the discharge were collected and analyzed at approximately weekly intervals at the same time that influent reclaimed water and impounded water were sampled. Although major releases of water for irrigation were made during four periods in August and September (see Table XXII, Appendix C), LTAC sampling dates coincided with a major release on only one occasion; September 16, 1970.

Results of analyses of samples collected on the approximately weekly schedule are reported in Appendix B. As noted in Chapter III, the various samples are identified as follows:

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TABLE VII

COMPARISON OF QUALITY OF INDIAN CREEK AND OTHER WATERS
(Selected Parameters, Summer 1969)

1	2	3	4	5	6	7	8	9	10
Component and Unit	Reclaimed Water 6/4-8/12/69	Indian Creek Reservoir 6/4-8/12/69	West Fork Carson River 68-69	East Fork Carson River 68-69	Indian Creek	Stevens Lake Outlet 6/20/68	Domestic[a] Well 8/15/56	Ward Creek[b] (Tahoe Basin)	Lake Tahoe[c]
DO, mg/ℓ	< 1	7 - 8		13.2 - 8.1	8.2 (9/5/69)	11.0 (9/5/69)	-	Sat.	7.3 - 9.9
BOD, mg/ℓ	< 1 - < 2	2.6	12.6 - 9.6	-	-	-	-	-	-
COD, mg/ℓ	25	35	-	-	-	-	-	1 ±	1 ±
NH_3-N, µg/ℓ	15,000	3000 +	-	-	60	-	-	15 ±	19
NO_3-N, µg/ℓ	1700	1550	700 - 300 (65-66 data)	-	0.0	0.0	-	20 ±	7 +
Total N, µg/ℓ	16,700	5900	-	-	108	108	-	110 ±	123
PO_4, µg/ℓ	175	25	200 (65-66 data)	150 - 10 (65-66 data)	-	-	-	7	4 -
Total P, µg/ℓ	112	63	-	-	160	160	-	20 ±	8 ±
Ca, mg/ℓ	52	37	8.6 - 4.2	19.6 - 6	-	-	7.8	5.7	9.3
Cl, mg/ℓ	27	18	1.7 - 0.8	3.5 - 1.3	0.0	0.0	0.5 - 0.8	0.5 -	1.6
Fe, µg/ℓ	12	14	-	-	-	-	-	1 ±	< 1
Alk., mg/ℓ	193	118	42 - 40	83 - 28	-	-	51	21	41
Hardness, mg/ℓ	-	-	33 - 14	80 - 21	-	-	30	-	-
TDS, mg/ℓ	-	-	41 (65-66 data)	109 - 52 (65-66 data)	-	-	80	-	-
pH	8.3	8.0	7.9 - 7.1	8.1 - 7.3	9.4	9.4	7.1	7.0 - 7.8	7.7
EC (micromhos at 25°C)	493	319	80 - 36	118 - 54	90	90	80.1	42 ±	80 ±

[a] Location 11N/19E - 35K1.

[b] Average 5 observations, summer 1969.

[c] Typical data, average 1969 20 observations.

1. Reclaimed (Tertiary effluent) water exported to Indian Creek Reservoir:

   Samples obtained at STPUD treatment plant } both are identified
   Samples obtained at Luther Pass pumping station } as L-III

2. Composite of four samples of impounded water in Indian Creek Reservoir collected from the top one-half meter of depth at Station 1 (Figure 6) - identified as C.

3. Continuous low-rate discharge water from reservoir - identified as B.

4. Impounded water taken at various depths indicated in the table, (Appendix B) at Stations 1, 2, and 3 (see Figure 6, Chapter III).

As noted in the table, some quality factors were evaluated by analysis of unfiltered samples; others by analysis of samples filtered as described in Chapter III. Results of important chemical analyses of Indian Creek Reservoir influent water (L-III), impounded water (C), and discharge (B) are summarized in the figures and tables hereinafter presented in this chapter.

BOD and COD

Table VIII, compiled from data in Appendix B, summarizes the values of BOD and COD observed on unfiltered L-III, C, and B samples.

TABLE VIII

SUMMARY OF OBSERVED VALUES OF BOD AND COD, INDIAN CREEK RESERVOIR, 10/3/68 - 3/26/70

Source of Sample	Symbol	BOD (mg/ℓ)			COD (mg/ℓ)		
		Maximum	Minimum	Mean	Maximum	Minimum	Mean
Influent Reclaimed Water	L-III	14	< 1	1 +[a]	51	< 1	23[c]
Impounded Water	C	15	< 1	3.1	57	1	27
Discharged[b] Water (daily)	B	25	< 1	5.8	102	< 1	28

[a] Nineteen of 26 observations < 1.

[b] Essentially leakage from reservoir.

[c] Substantially greater than reported by STPUD, Table XXX, Appendix D. Slightly different techniques used. COD test notorously variable in results at values less than 50 mg/ℓ.

From the table it is evident that the BOD of the reclaimed water exported (L-III) was extremely low, averaging only about one mg/ℓ. Except for the single high value of 14 mg/ℓ, no value greater than three mg/ℓ appears in the 26 observations reported in Appendix B. As might be expected, other inputs to the reservoir, plus organic life in the water, contributes to a greater average BOD in the surface water (top one-half meter). A still greater BOD appears in the leakage, or continuous discharge from the reservoir (sample B). This is also to be expected because the discharged water was drawn from the depths of the reservoir between the biologically active surface and bottom zones. Unfortunately no BOD observation was made of the discharged water on September 16, while water was being released at a rate of 12.7 cfs (Table XXII, Appendix C). Consequently the effect of storage on BOD cannot be evaluated from existing data.

The mean and minimum values of COD in Table VIII cannot be said to differ from influent to discharge of the reservoir. The significance of the maximum values can best be postulated by reference to Figure 7. Here the general grouping of the three curves explains the similarity of the means shown in Table VIII. The general similarity of influent (L-III) and impounded water (C) confirms the conclusion previously drawn from Table IV that the quality of impounded water is normally more influenced by reclaimed water than by surface runoff.

Fluctuations in the influent COD, which appear to govern the fluctuations in the reservoir system, are attributable to the normal lack of uniformity of product from any waste water treatment plant under conditions of fluctuating population load such as characterizes the Lake Tahoe Basin, together with the day-to-day contingencies of plant operation.

High values of COD in impounded water which appear in July might be explainable by an increase in aquatic biota following warming of the water in June (Figure 8). However, Figures 9, 11, 12, and 13 (clarity, SS, VSS, and iron) all show that aquatic life was most pronounced in mid-June. It is possible that dead organic matter in relatively large agglomerations was responsible for the July peaks in COD of impounded water, but data are insufficient to document such a possibility. More likely the answer lies in dissolved oxidizable matter which does not affect water clarity to an important degree. A conclusion that this was the case is supported by the fact that during the preceding month DO reached zero in the water at the bottom of the reservoir and some three-in. of benthic sludge was present. Ammonia in the water was low but no observations were made of volatile acids and other degradation products which might exert a COD.

High values of all three curves in late October indicate a well-mixed system which could result from good local vertical mixing of influent and impounded water in the deep zone of the reservoir. Quite probably the high value of COD of impounded water (C) in February is the result of stirring up of sediments by an aeration system installed in January to provide oxygen for the fish population of the reservoir.

The exceptionally high value of COD (102 mg/ℓ) observed in the discharge water on September 25, 1969 is almost certainly the aftermath of discharging 176 acre-ft of water from the reservoir during the period September 16 through September 23. (See Table XXII, Appendix C.) It would be surprising if such a drastic disturbance of the bottom equilibria did not lead to a temporary increase in suspended solids. Figure 11 shows that such an increase did indeed occur; and Figure 12 shows that the volatile solids more than doubled on that occasion.

From Figure 7 it may be generally concluded that the observed COD of influent, impounded, and discharged water of Indian Creek Reservoir responded in a rationally explainable manner; and that during the period of observation the characteristics of the reservoir water were influenced principally by the influent reclaimed water from the STPUD. Such a conclusion is supported by Table IX, compiled from Appendix D, which shows mean values of COD and of other water quality factors discussed hereinafter. Values of 22, 25, and 21 are reported for influent (L-III), impounded water (C), and discharge (B), respectively. These differ from the mean COD values (23, 27, and 28) reported in Table VIII because they represent the mean of monthly averages, whereas Table VIII reports the average of all analyses without regard to the variation in number of samples from month to month. Nevertheless, both Table VIII and Table IX support the same conclusion — that there was no significant difference in the average COD of the three types of samples during the period of study.

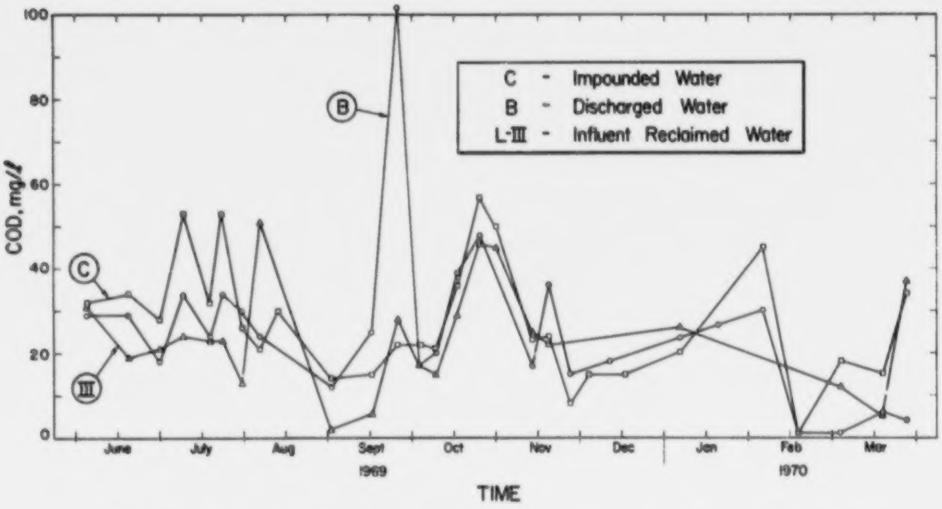

FIGURE 7. VARIATION IN COD, INDIAN CREEK RESERVOIR

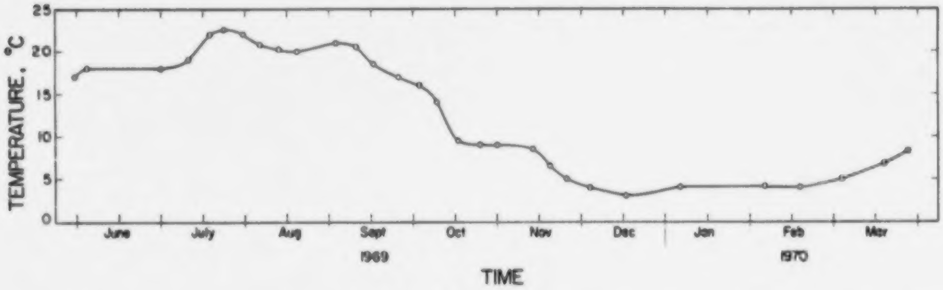

FIGURE 8. VARIATION IN SURFACE WATER TEMPERATURE (TOP 1/2 METER), INDIAN CREEK RESERVOIR

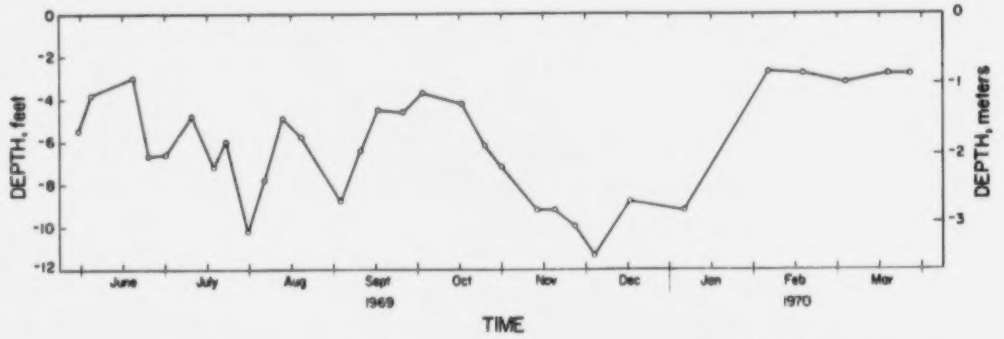

FIGURE 9. CLARITY OF INDIAN CREEK RESERVOIR, SECCHI DISK AT STATION 1 (FIG. 6)

TABLE IX

MEAN OF MONTHLY AVERAGE VALUES OF VARIOUS WATER QUALITY FACTORS AT INDIAN CREEK RESERVOIR OBSERVED BY LTAC DEMONSTRATION GRANT LABORATORY, JUNE 1969-MARCH 1970

Water Quality Factor	Reclaimed Water (L-III)	Impounded Water (C)	Discharged Water (B)
Cond. (μ mhos)	524	359	354
pH (range)	7.4 - 8.8	7.7 - 8.5	7.6 - 8.4
Cl (mg/ℓ)	27	22	22
Ca (mg/ℓ)	58	42	42
Alk. (mg/ℓ)	215	122	121
Inor. C (mg/ℓ)	52	30	29
Unfiltered Sample			
TSS (μg/ℓ)	1,292	4,083	4,765
VSS (μg/ℓ)	1,089	2,245	1,815
Org. N (μg/ℓ)	723	1,094	906
NH_3 (μg/ℓ)	18,160	3,498	3,580
Total P (μg/ℓ)	162	62	109
COD (mg/ℓ)	22	25	21
Filtered Sample			
Org. N (μg/ℓ)	647	909	898
NH_3 (μg/ℓ)	17,942	3,439	4,006
NO_2-N (μg/ℓ)	52	236	276
NO_3-N (μg/ℓ)	612	2,657	2,552
Total Inor. N (μg/ℓ)	18,568	6,334	6,819
Total N (μg/ℓ)	19,313	7,241	7,717
PO_4 (μg/ℓ)	126	37	67
Total P (μg/ℓ)	148	51	86
Fe (μg/ℓ)	11	9	13

Temperature

Variation in temperature of the surface stratum of water in Indian Creek Reservoir during the period June 1969 – March 1970 is summarized graphically in Figure 8. Here a normal seasonal pattern is evident. From early June until the middle of September 1969 the midday (1100 – 1300 hr) water temperature was consistently at or above 18°C hence highly favorable to the growth of algae. By the 15th of October, however, the temperature had declined to less than 10°C. From November 15 until near the end of March 1970, temperatures were at or below the 8°C level at which algal growth becomes temperature limited and proceeds slowly if at all in most species.

Clarity of Reservoir Water

Secchi disk observations reported in Appendix B are shown in a time sequence in Figure 9. Because samples were normally taken between the hours of 1100 and 1300 on sampling days, and the light intensity (see Appendix B) were usually high the variation in Secchi disk readings appearing in Figure 9 cannot be directly seasonal or diurnal in origin in the way that temperature is seasonal. That they are, however, definitely a function of season is shown in Figure 10 in which water clarity and suspended solids (SS) are compared. Although there is a variability in the clarity at any given SS value, which is explainable in terms of water surface disturbance and other variables, the general envelope curve takes the form to be expected of a clarity-turbidity relationship.

Comparison of Figure 9 with Figure 11 also shows the expected inverse relationship between water clarity and suspended solids in the impounded water (curve C), the lowest Secchi disk readings appearing in mid-June, mid-August, October, and Feb-March when peaks occurred in the suspended solids curve.

Suspended Solids (Total SS)

Results of the suspended solids analyses reported in Appendix B are presented graphically in Figure 11. Monthly averages appear in Appendix D, from which the mean values summarized in Table IX were abstracted. From Table IX it appears that during the period April 1969 through March 1970 reclaimed water entered Indian Creek Reservoir with a mean value of suspended solids of about 1200 μg/ℓ. In the impounded water this increased to some 4100 μg/ℓ; and remained at about this same value (4800 μg/ℓ) at time of discharge. The obvious reason for this difference – the growth of living cells – is documented by a drastic reduction in the ammonia concentration without a corresponding increase in other forms of nitrogen in filtered samples.

From Figure 11 it may be seen that reservoir and effluent SS are generally closely related and are seasonal in nature. Also that they are obviously a function of some characteristic of the reclaimed water other than its suspended solids. There is no reason why peaks in the impounded water SS curve (curve C) should coincide with those of the discharge water (curve B) since one represents a quality condition near the water surface; the other near the bottom. Nevertheless, there is some tendency for the two to react in a similar fashion. Attention has been previously called to the relationship between the variation in suspended solids and the temperature, clarity, and COD of the impounded water. Relationships between SS and various other quality factors are noted in sections of the report which follow.

Volatile Suspended Solids (VSS)

Volatile suspended solids being a function of total suspended solids in a situation such as pertains in Indian Creek Reservoir, it is to be expected that the VSS and SS curves should differ only in scale. Figure 12, when compared with Figure 11, shows this to be the case. However, in August 1969 and again in March 1970 the percentage of volatiles in the total SS is extremely high whereas in June the ratio of SS to VSS was about 1.5 to 1 and in October more than 3 to 1. Reasons for this variation are not self-evident nor adequately documented. However, it may be significant that on the October 8, 1969 sampling date strong northerly winds and an 18-in. wave amplitude prevailed (see Table VI). This may have stirred up inorganic sediments. On the other hand, a strong southerly wind in December produced no similar effect; but then heavy surface runoff occurred in December (Table IV) and its content of solids is unknown. Although the causes of observed variation in SS/VSS ratios cannot be fully identified there is nothing implausible about the observed VSS data.

Figure 14 shows that no identifiable relationship exists between VSS and COD. This further supports the conclusion that soluble degradation products, as in the case of July 1969 (see Figure 7 and discussions of COD and Clarity), account for an important fraction of observed COD.

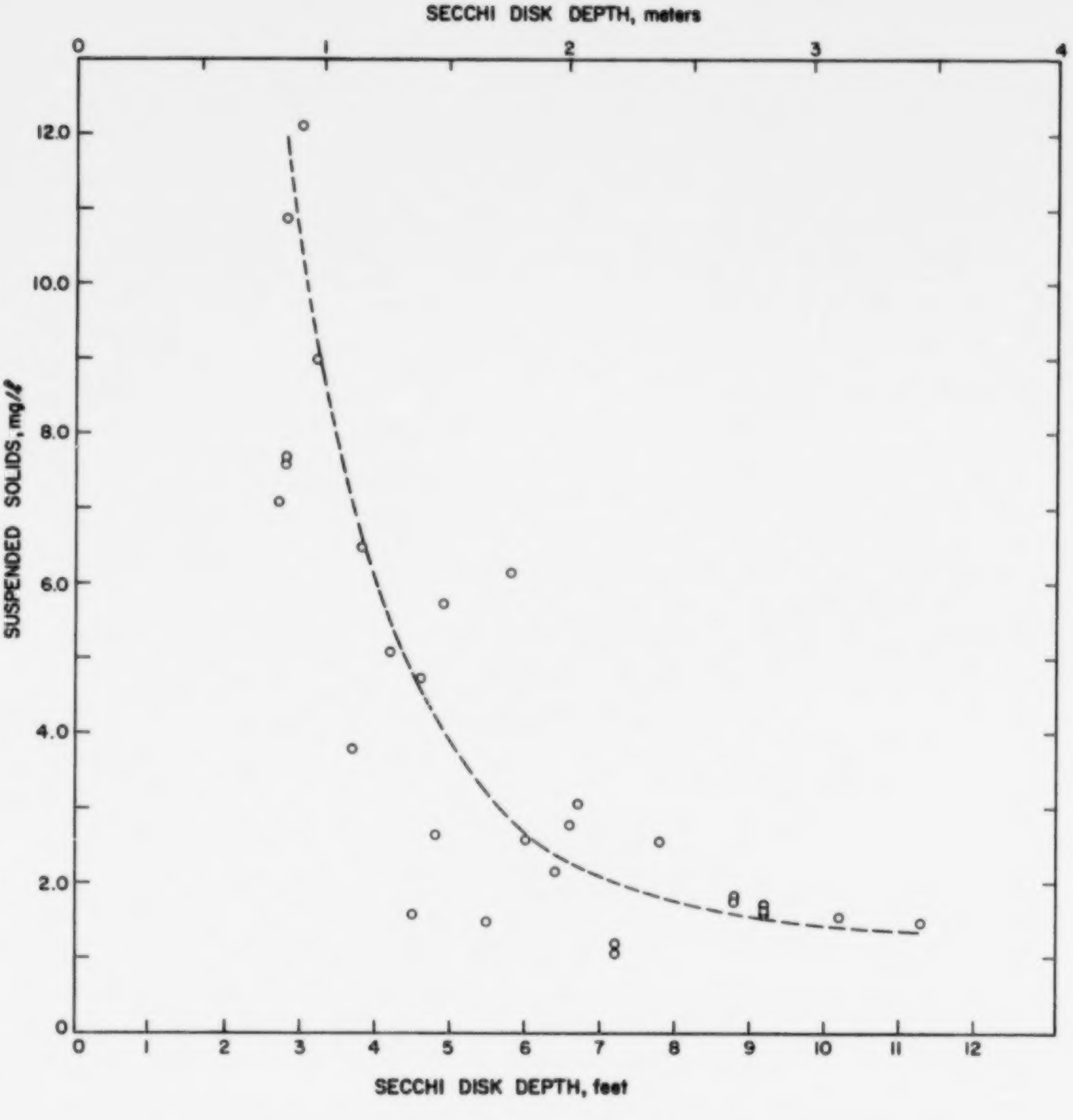

FIGURE 10. CLARITY OF WATER (SECCHI DISK) AS A FUNCTION OF SUSPENDED SOLIDS

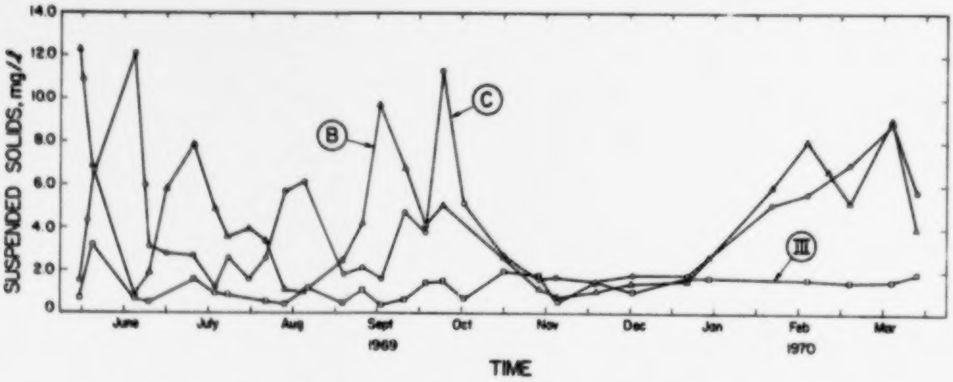

FIGURE 11. VARIATION IN SUSPENDED SOLIDS, INDIAN CREEK RESERVOIR

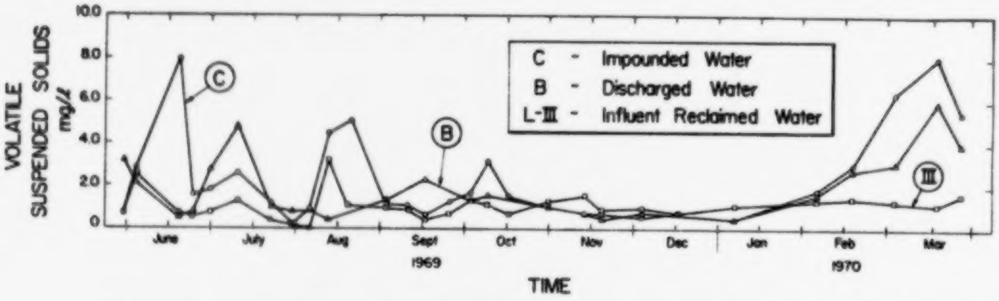

FIGURE 12. VARIATION IN VOLATILE SUSPENDED SOLIDS, INDIAN CREEK RESERVOIR

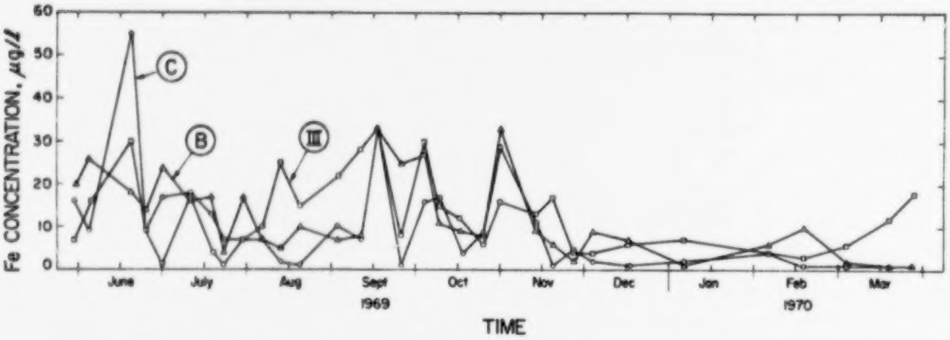

FIGURE 13. VARIATION IN IRON CONCENTRATION, INDIAN CREEK RESERVOIR

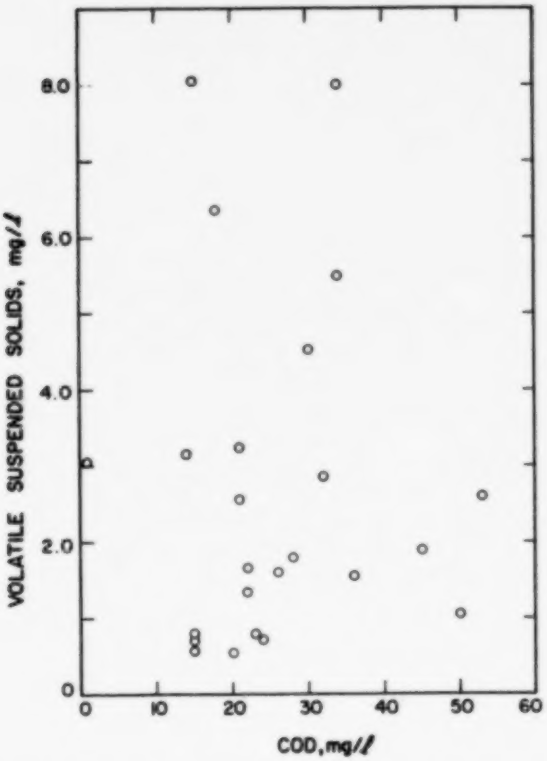

FIGURE 14. RELATIONSHIP BETWEEN VSS AND COD, INDIAN CREEK RESERVOIR

Iron

Table IX shows that over the year of study the iron content of the influent reclaimed water averaged higher than that of the impounded water, and somewhat less than that of the discharged water. Assuming these data to reflect accurately the true situation it must be postulated that the influent iron concentration was reduced in the impounded water by a combination of surface runoff and incorporation into living cells (not measured in filtered samples). Thereafter, the discharge appeared greater as a result of release of iron from degrading organic matter; and the system was either not in equilibrium during the period of study or additional iron entered the system from soil leaching. Existing data are not sufficiently refined to permit a rigorous evaluation of this postulate. Nevertheless, some further evidence may be obtained from a consideration of Figure 13 and other curves herein presented.

Figure 13 shows that the iron content of reclaimed water was variable, with a general but roughly defined tendency to be higher during the summer and fall months when the visitor load on the Lake Tahoe Basin is greatest. During this same period when biological growth in the reservoir might be greatest there was a definite tendency for impounded and discharge water (curves C and B) to parallel each other, but little tendency to follow the pattern of influent iron. In June 1969 the greatest concentration of iron observed during the year of study coincided with similar high concentrations of SS and VSS (Figures 11 and 12), indicating that the presence of iron was related to the suspended solids. However, because the iron was observed in a filtered sample it could not have been incorporated in the cells of algae. Following June 1969 there was a pronounced tendency of iron to decrease when SS and VSS increased (see Figures 11, 12, 13). This supports the logic that iron may have been an important factor in the production of biota in the reservoir. From December 1969 until the end of the sampling period reported (March 1970) it is not evident from Figure 13 where the iron was located in the system. Presumably that taken up by living cells during the summer was precipitated on the reservoir bottom. Incoming iron during January 1970 and thereafter is not fully reflected in the impounded water. Ice cover and poor mixing generally may account for the observed results. Reduction in an already low concentration of iron accompanied a rise in suspended solids in March 1970, although the relationship is not clearly identifiable.

Concerning iron in Indian Creek Reservoir it may be concluded that it plays an important role in the life cycle of biota which appear in the surface stratum of the impounded water.

Chlorides

Table IX shows that the chloride concentration in influent reclaimed water averaged 27 mg/ℓ during the April 1969 to March 1970 period of study. At the same time both the impounded and the discharged reservoir water contained 22 mg/ℓ of chlorides. The difference is presumably due to dilution of the reclaimed water by precipitation and surface runoff. That this was indeed the case may be demonstrated by reference to Table IV. From data summarized in the table it may be computed that for the period April to December 1969, 1994 acre-ft of reclaimed water, 392 acre-ft of surface water, and 152 acre-ft of direct precipitation entered the reservoir. At the same time 362 acre-ft of water were lost by evaporation. Assuming 27 mg/ℓ-Cl in reclaimed water; 2 mg/ℓ-Cl in surface runoff (Table XXVI, Appendix C); and no chlorides in rainfall or evaporated water, the chloride concentration in the water impounded during the period would have been 25 mg/ℓ. This checks the observed concentration in the reservoir at the end of December (Figure 15) — a fact which may be more coincidental than exact, due to the large volume of water already impounded at the beginning of the period. Nevertheless, it is evident that dilution is the important factor in the chloride balance of Indian Creek Reservoir.

The foregoing conclusion is supported by data summarized graphically in Figure 15, which represents the results of approximately weekly analyses reported in Appendix B. The figure shows that for the entire period reported the influent reclaimed water was, with but minor exceptions, always higher in chlorides than the impounded and discharged water. The difference between influent and impounded water values is greatest during the June 1 to October 1 period. Table IV shows that throughout that season the volume of impounded water remained at a high level and within a depth range of 49.2 to 51.0 ft. Simultaneously there was little runoff input and evaporation was at a maximum rate (Table IV). The result, as shown in Figure 15, was a slow but steady increase in the chloride content of impounded water, not evident in the influent, indicating that mixing of influent with the impounded water already present took place during the summer although the input was sufficient essentially to replace the previous impoundment. The essential identity of impounded water and discharged water curves during that period likewise supports this conclusion.

During October and November, when water temperatures were declining most rapidly, the chloride content of the influent water rose rapidly. Because a similar rise was evident in the discharged water, and the volume of water in the reservoir remained too large to be profoundly affected by immediate chloride inputs, it must be concluded that a profound mixing occurred which involved water masses not previously accurately described by sample C, taken in the vicinity of Station 1 (Figure 6, Chapter III).

The decline in chloride concentration in impounded water in December, with a loss of its former close relationship to that of discharged water, is a direct result of an increase in the runoff/influent water ratio from the 0-10 percent range which prevailed during the summer, to a value in excess of 100 percent. As the figure shows, this event did not affect the lower stratum of water from which the small discharge originated.

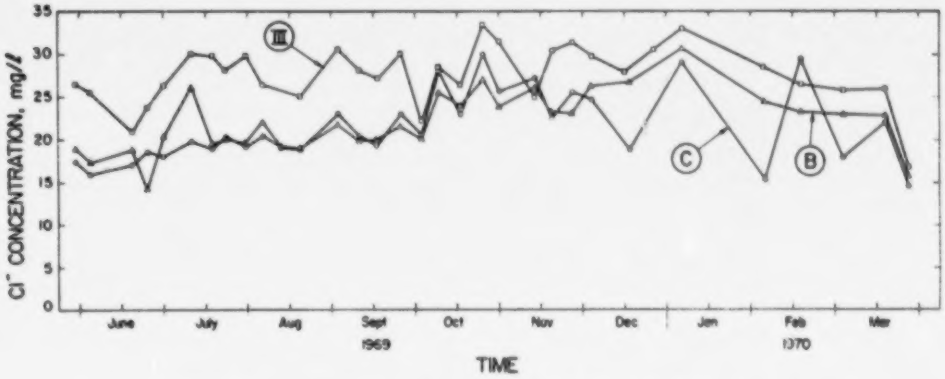

FIGURE 15. VARIATION IN CHLORIDE CONCENTRATION, INDIAN CREEK RESERVOIR

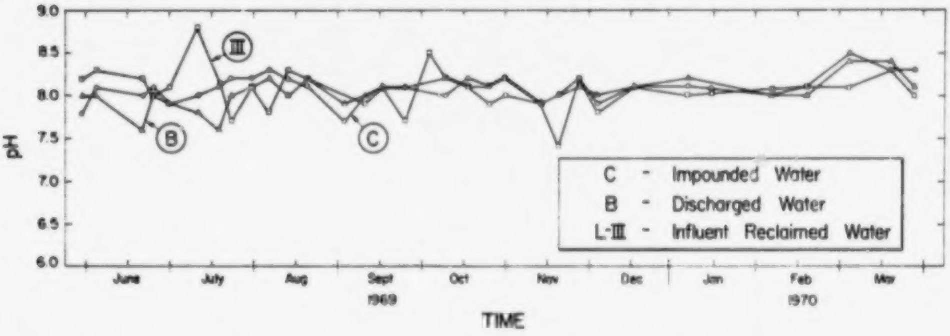

FIGURE 16. VARIATION IN pH, INDIAN CREEK RESERVOIR

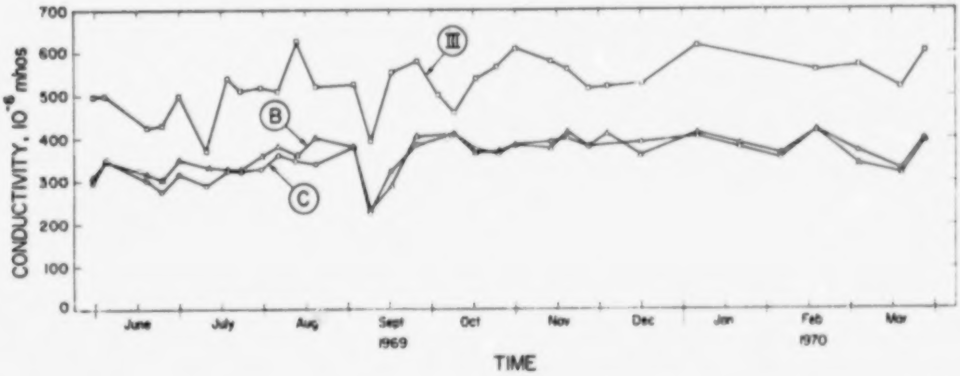

FIGURE 17. VARIATION IN CONDUCTIVITY, INDIAN CREEK RESERVOIR

Ice cover which inhibited mixing in January accounts for the poor mixing which Curve C indicates for that month. Thereafter, the erratic nature of the curve reflects both renewed mixing as water temperatures started to rise, and the effect of less frequent sampling imposed by the weather.

From the results of the chloride analysis, compared with hydrological and climatological data for the same period, it may be concluded that the observed data tell an exceptionally clear and rational story of the seasonal behavior of Indian Creek Reservoir.

pH

Variation in pH of reclaimed, impounded, and discharged waters of Indian Creek Reservoir are summarized in Table IX and Figure 16. Table IX (compiled from Tables XXVII, XXVIII, and XXIX, Appendix D) shows the following range of pH values observed from April 1969 – March 1970:

Reclaimed water influent . . .	7.4 – 8.8
Impounded water	7.7 – 8.5
Discharged water	7.6 – 8.4

Figure 16 presents the results of the weekly schedule of sampling and analysis for the period beginning in June 1969 and ending in March 1970. As might be expected, the greatest variation occurred in the influent reclaimed water (L-III). Peaks and troughs of the L-III curve were, of course, damped out in the greater volume of impounded water. In general, the impounded water and discharged water showed little difference in pH, indicating that in the deep water where the discharge originated there was either good mixing, limited biodegradation products, or both. During the months of June and July, when dissolved oxygen is known to have been absent in the lower strata, the pH of surface (Curve C) and bottom water (Curve B) diverged in a normal fashion. This supports the conclusion that pH is a sensitive parameter of the limnological characteristics of Indian Creek Reservoir.

Conductivity

Both Table IX and Figure 17 show that the conductivity of impounded and discharged water were essentially the same throughout the period of study. As in the case of pH, both were generally insensitive to transient variation in the conductivity of influent reclaimed water. The consistent drop in conductivity of influent water as it mixed with impounded water is a function of both dilution and other factors which combined to reduce such factors as alkalinity and carbon.

Monthly average values of conductivity reported in Tables XXVIII and XXIX, Appendix D, for impounded and discharged water range from 414 to 229 μ mhos/cm at 25°C (.42 – .23 m mhos/cm). This is within the 0.25 + 0.75 m mhos/cm. range reported by Eldridge [17] to characterize about half of the irrigation waters used in western irrigation. It is also in the range where the salinity effects are reported by the USDA [18] to be mostly negligible on field, vegetable, and forage crops.

It is therefore concluded that in terms of conductivity, water impounded in Indian Creek Reservoir is of good quality for agriculture.

Calcium

Figure 18 summarizes the concentration of calcium observed in reclaimed, impounded, and discharged water at Indian Creek Reservoir during the 1969-1970 period herein reported. As in the case of all quality factors observed, the transient fluctuations in influent concentration are damped out in the mass of impounded water.

The influent concentration is characteristically high, and the impounded water and discharged water curves are close together except when some unusual event occurs. Such events took place in August and September when water was released for agriculture at some four times the influent rate (Table XXII, Appendix C).

Values reported in Appendix B, on which Figure 18 is based, were obtained from sampling immediately following periods of water release. Moreover, the physical relationships between sampling station 1, reclaimed water influent point, and reservoir discharge pipe (Figure 6, Chapter III) introduce effects which are difficult to isolate and evaluate. Stirring up of bottom sediments is to be expected, as is an interruption of normal mixing patterns. Therefore, although Curves B and C, Figure 18, reflect the fact that releases occurred in the August-September period, the variation from more normal periods is not readily interpreted in terms of reservoir limnology.

The question of whether dilution alone, or dilution plus precipitation of calcium carbonate, accounted for the difference between influent and reservoir concentration of calcium was explored by the same approach applied to chlorides, for the period June to December 1969. Using the values computed from Table IV (1994 acre-ft reclaimed water influent; 392 acre-ft surface runoff; 152 acre-ft direct precipitation; and 362 acre-ft evaporation) and calcium concentrations from Table XXVI, Appendix C (10 mg/ℓ for surface runoff) and Table XXVII, Appendix D (58 mg/ℓ for reclaimed water) it is calculated that the concentration of calcium in the 2548 acre-ft of mixture should be 46 mg/ℓ on December 31, 1969. If the actual volume of 2300 acre-ft is used, the Ca concentration would be 50+ mg/ℓ. Figure 18 shows the observed value (Curve C) to be about 49 mg/ℓ. As in the case of chlorides there is no way to determine how much of the water in the reservoir on December 31, 1969 was there also on June 5, when the Ca concentration was 34 mg/ℓ. However, enough water did enter the reservoir from June to December theoretically to replace the earlier impoundment, and its effect might be predominant. In any event all factors considered, including the calculated rough check, it is concluded that the calcium content of the reservoir in comparison with that of the influent reclaimed water is the result of dilution rather than any major precipitation of calcium.

Alkalinity

Variation in the alkalinity in the Indian Creek Reservoir waters is summarized in Figure 19. Variability of the influent reclaimed water is again evident; and impounded and discharged water are generally the same except that the relationship was disturbed during the August release of water.

Utilizing the quantity relationships discussed in preceding sections on chlorides and calcium together with values of alkalinity from Table XXVII, Appendix D (215 mg/ℓ in reclaimed water) and Table XXVI, Appendix C (30 mg/ℓ in surface waters), it is computed that the alkalinity on December 31 would have been 169 mg/ℓ on the basis of dilution alone. Figure 19 indicates that the observed value (Curve C) was about 140 mg/ℓ, or 83 percent of the computed value. The fate of the remainder of the alkalinity is then the unanswered question.

Assuming on the basis of both chlorides and calcium, findings that dilution does account for the decrease in calcium, precipitation of calcium carbonate could not account for the apparent loss in alkalinity. Nor could precipitated $CaCO_3$ in the recarbonated reclaimed water be the answer, because the calcium and alkalinity data were obtained from filtered samples. Alkalinity in the exported reclaimed water is in the bicarbonate form as a result of recarbonation at the STPUD plant. However, no analyses were made for sodium or magnesium, hence it is impossible to be certain that all the calcium is accounted for by any study of the data on alkalinity. The answer might, however, be found in an accounting for the inorganic carbon.

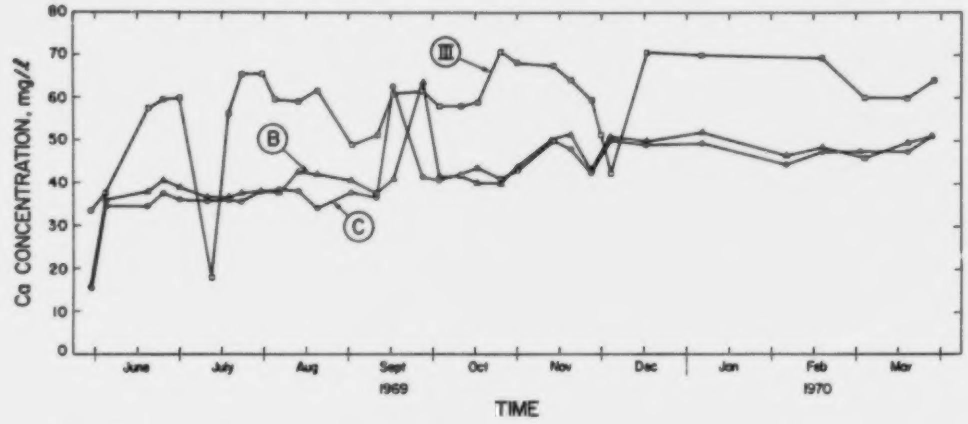

FIGURE 18. VARIATION IN CALCIUM CONCENTRATION, INDIAN CREEK RESERVOIR

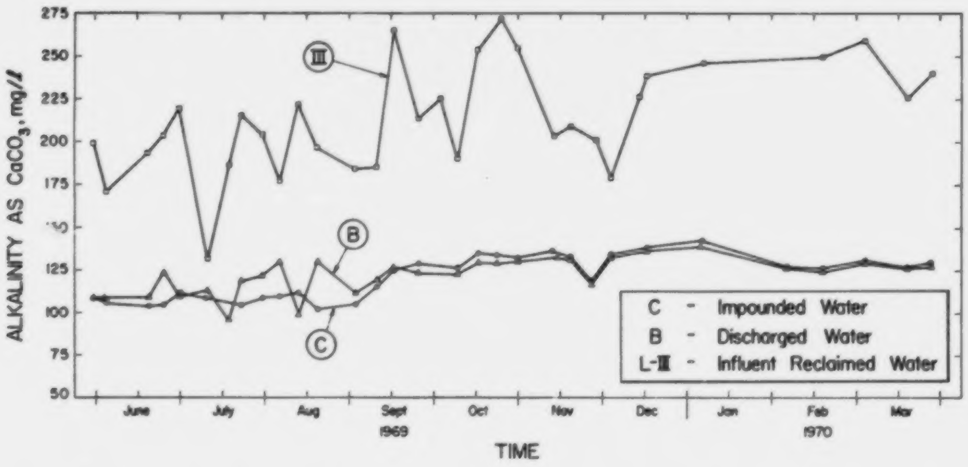

FIGURE 19. VARIATION IN ALKALINITY, INDIAN CREEK RESERVOIR

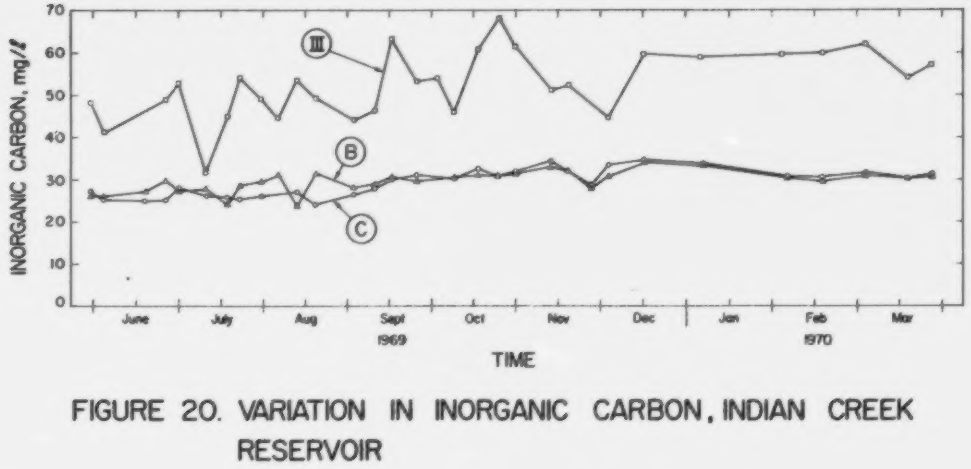

FIGURE 20. VARIATION IN INORGANIC CARBON, INDIAN CREEK RESERVOIR

Inorganic Carbon

Figure 20 shows that the inorganic carbon content of reclaimed, impounded, and discharged water. Plotted values were computed rather than observed, on the basis that the carbon is in the bicarbonate radical of alkalinity. From Table XXVII, Appendix D, the inorganic carbon in reclaimed water is found to be 50(-) mg/ℓ. Assuming that all inorganic carbon in surface waters (Appendix C) is in the total hardness minus (SO_4), a value of 5 mg/ℓ is estimated for carbon. Utilizing these values, and assuming no inorganic carbon in precipitation on the reservoir or in evaporated water, the theoretical carbon content of the impounded water on December 31 is computed by the procedure described in the section on chlorides to be 47 mg/ℓ. Figure 20 shows that the actual value on that date was 34 mg/ℓ. Thus the actual carbon concentration is 73 percent of the computed value – a little less than as in the case of alkalinity. Errors of assumption and of sampling and analysis, of course, make the difference of alkalinity and inorganic carbon shortages a coincidence rather than a precise check, but the evidence is impressive that the loss of carbon was the cause of unaccounted for alkalinity.

Table XVII, Appendix A, shows that alkalinity appreciably exceeded total hardness in the exported water and that sulfates were present. Therefore, bicarbonates other than calcium bicarbonate were present in the alkalinity. Some of the calcium may have been associated with SO_4, but most of it was certainly in the bicarbonate form.

The conclusion seems inescapable that bicarbonate alkalinity was being used as a source of carbon by the biota of Indian Creek Reservoir during the period of study.

Phosphorus

Because phosphorus removal is one of the processes utilized by STPUD in reclaiming the water exported to Indian Creek Reservoir, total phosphorus seldom exceeds 200 μg/ℓ. Table IX shows that during the period April 1969 to March 1970 the average value of total phosphorus in influent reclaimed water was 148 μg/ℓ. Orthophosphate for the same period averaged 126 μg/ℓ. Table XVII, Appendix A, and Table XXVII, Appendix D, present the variation in phosphorus in reclaimed water in greater detail for a longer period of record. Figures 21 and 22 show that on three occasions during the study some operational problems at the plant resulted in abnormally high peaks in the L-III curve.

Phosphorus being a nonconservative material in that it enters into life cycles and may spend a good portion of the cycle in the benthic sludge or in living cells cannot be accurately traced by the dilution computations previously applied to more conservative elements. A rough check might be made of dilution effects from the calcium, alkalinity, and inorganic carbon data. In each case dilution theoretically reduced the concentration to 80(+) percent of the influent value.

Applying this constant to phosphorus data given in Table IX it might be expected that dilution alone would have reduced PO_4 from 126 to 100 μg/ℓ by December 13, 1969, and total phosphorus from 148 to 120 μg/ℓ. Actual values from Appendix B, on which Figures 21 and 22 are based, show 51 μg/ℓ and 60 μg/ℓ, respectively. The value of such a rough computation is simply to show that no irrational values appear in the data. The role of phosphorus in life processes leads to the expectation 1) that actual phosphorus concentrations will be less than dilution can account for; and 2) that phosphorus in the bottom of the reservoir might exceed that in the overlying water. Figures 21 and 22 show that this was indeed the case. Further evaluation of phosphorus concentration as a nutrient in Indian Creek Reservoir is herein delayed until a subsequent more appropriate section dealing with biota of the reservoir.

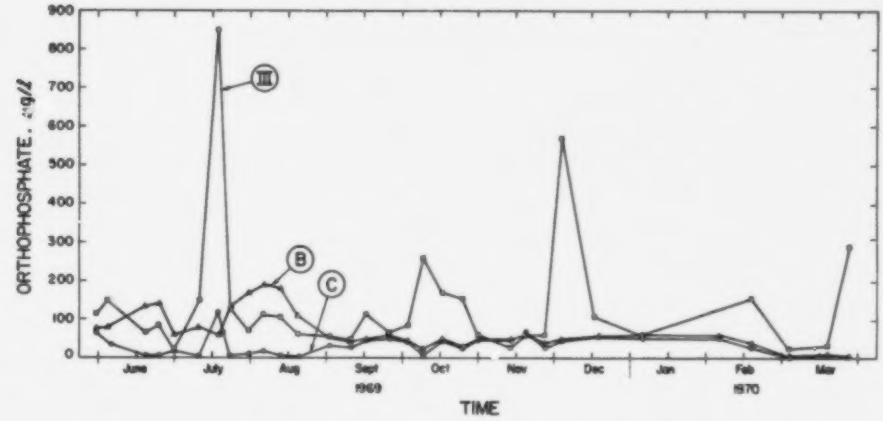

FIGURE 21. VARIATION IN CONCENTRATION OF ORTHOPHOSPHATE, INDIAN CREEK RESERVOIR

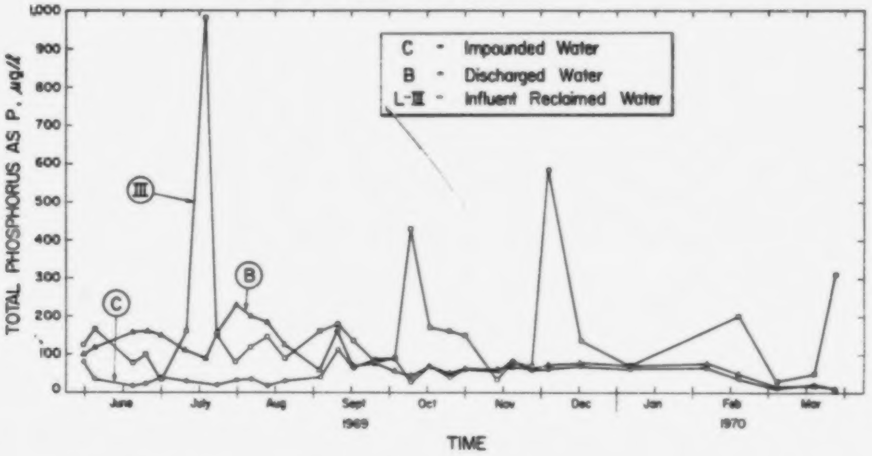

FIGURE 22. VARIATION IN CONCENTRATION OF TOTAL PHOSPHORUS, INDIAN CREEK RESERVOIR

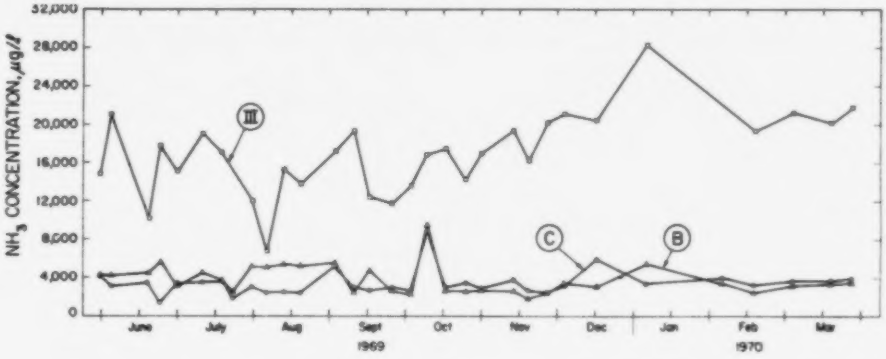

FIGURE 23. VARIATION IN CONCENTRATION OF AMMONIA, INDIAN CREEK RESERVOIR

Nitrogen Compounds

1. Ammonia

Figure 23 summarizes the variation in ammonia content of influent, impounded, and discharged water during the approximately weekly sampling period, June 1969 to March 1970. As in the case of other quality factors discussed in preceding sections the transient fluctuations in reclaimed water are damped out in the impounded water. In August ammonia appears to have been generated at the lower depths, but disturbance due to irrigation withdrawals make such a conclusion highly tentative.

By applying the 80 percent dilution observation to data in Table IX and Table XXVII, Appendix D, it develops that dilution alone would have reduced ammonia to 14,000 μg/ℓ on December 31 instead of the 3420 μg/ℓ. Again this observation serves only to check the validity of the data and to suggest that a very large fraction of the NH_3-N is active in the biological cycle discussed in a subsequent section.

2. Nitrites Plus Nitrates

Table IX, Appendix B, and Appendix D show that the values for nitrite nitrogen averaged less than 10 percent of those for nitrates (e.g., 52 vs 612 μg/ℓ, Table IX). The two forms of nitrogen are therefore combined for presentation in Figure 24. The figure shows that except for one month in July-August 1969, the influent nitrite-nitrate was extremely small. The vastly greater concentrations appearing in the impounded and discharged water is therefore largely due to the oxidation of ammonia by the biota of the reservoir. No particularly profound conclusions may be reached by considering the B and C curves in the absence of biological data. There is some indication in August that departure from the normal relationship of the B and C samples noted in other figures is reflected in the $NO_2 + NO_3$ concentration as well. But as before, the meaning in terms of limnology of Indian Creek Reservoir is not fully revealed.

3. Total Nitrogen

As in the case of ammonia the 80 percent factor applied to total nitrogen values in Table IX shows the limited effect of dilution (i.e., 16,500 μg/ℓ calculated, vs 7739 μg/ℓ reported at the end of December). The reason, of course, is that much of the total nitrogen was in the form of ammonia. Consequently, the total nitrogen in impounded and discharged water produces curves similar to those of ammonia, except that they are more uniform from week to week and show a slight tendency for increasing values over the period which is probably not significant.

4. Organic Nitrogen

Organic nitrogen is the only major quality factor herein presented, Figure 26, in which the concentration in the impounded and the discharged fluctuated as wildly as that in the influent reclaimed water. In the summer there was a very rough tendency for either the impounded water or the discharged water curves to peak with the influent curve; in the fall the reverse was the case. In December the greatest concentration was in the overlying water but by January it was in the bottom strata. There is a definite tendency to higher than average organic nitrogen during the summer and fall months, and less than average in the winter. On the basis of Figure 26 it must be concluded that organic nitrogen is not a good parameter by which to describe the limnology of Indian Creek Reservoir.

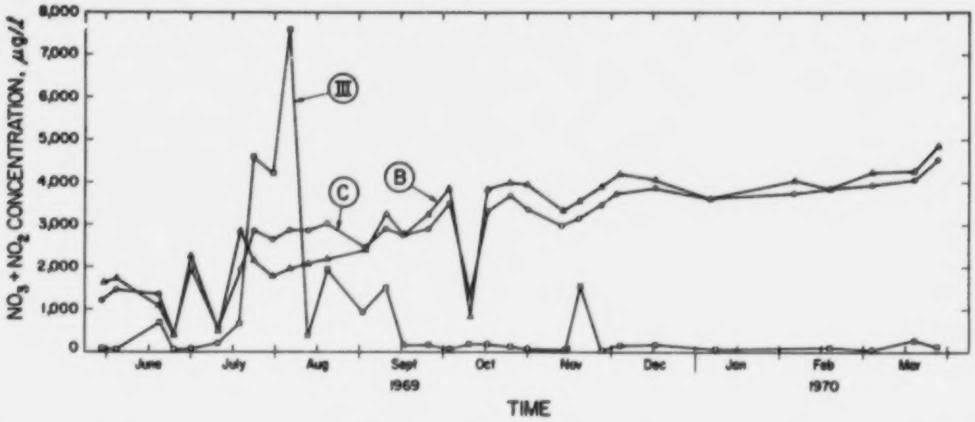

FIGURE 24. VARIATION IN CONCENTRATION OF NITRATE + NITRITE NITROGEN, INDIAN CREEK RESERVOIR

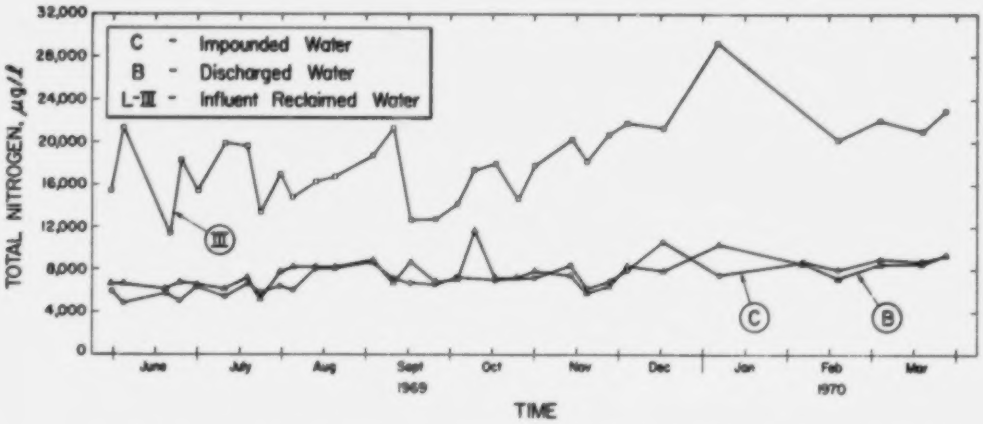

FIGURE 25. VARIATION IN CONCENTRATION OF TOTAL NITROGEN, INDIAN CREEK RESERVOIR

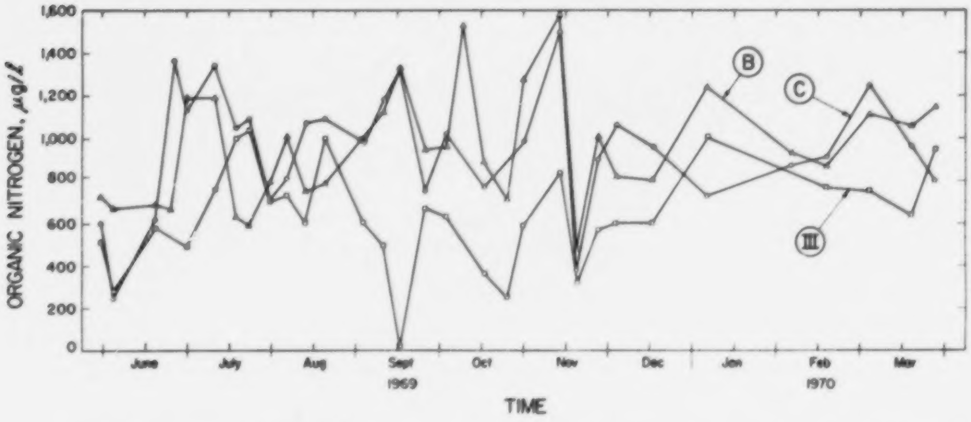

FIGURE 26. VARIATION IN CONCENTRATION OF ORGANIC NITROGEN, INDIAN CREEK RESERVOIR

5. Ammonia Plus NO_2-N and NO_3-N

Figure 27 represents a plotting of the combined NH_3, NO_2, and NO_3 nitrogen of Figures 23 and 24. As might be expected from the comparative concentration of NH_3 and other forms of nitrogen (Appendix B and Table IX) ammonia overwhelms the others and there is great similarity between Figures 23 and 27. Influent fluctuations are damped out; and impounded water and discharged water curves stay together except during the August-September period of discharge. At that time disturbance of the benthos leads to a greater concentration of nitrogen in the discharged water, as might rationally be predicted when an organic sludge is present.

Dissolved Oxygen

Dissolved oxygen data for influent reclaimed water, impounded water, and discharged water for weekly and 24-hr sampling dates are presented in Appendix B. Values reported for influent reclaimed water prior to November 1969 are suspect because the technique used in sampling from a pressure line may have resulted in a variable degree of aeration of the sample. After this source of error was eliminated the influent DO varied within a range of 2(+) to < 1 mg/ℓ. These direct values cannot be related to oxygen saturation in the absence of temperature data; and collecting such data at any point beyond the Luther Pass Pumping Station, 17 miles from Indian Creek Reservoir, was beyond the feasible scope of the project.

The variation in dissolved oxygen in surface and bottom strata during the weekly sampling program from June 1969 to March 1970 is shown graphically in Figure 28. For purpose of data interpretation, the DO saturation curve for water at 5600 ft elevation and at the temperatures observed at the one-half meter depth is included in the figure.

No particularly revealing conclusions can be drawn from Figure 28. The rough similarity of the impounded and discharged water curves indicate that the careful sampling of water from the discharge pipe was reasonably successful. It may be that the results are somewhat optimistic as there was no way to check the possible oxygen uptake of water flowing through the dam in a partially filled pipe, albeit under nonturbulent conditions.

Causes of the extremely high values of DO reported just before November 1, 1969 are not adequately explained. A recheck of the data and discussions with personnel involved reveals no identifiable error. Figure 9 shows that the impounded water was exceptionally clear at that time, and Figure 8 shows that the temperature stood at 9°C. Thus any unobserved algal bloom was not the cause. Curves for alkalinity, conductivity, calcium, COD, iron, and organic nitrogen showed peaks on October 30; and total phosphorus reached a low value. However, DO is not directly related to these parameters.

Table VI shows that wind was not blowing on October 24 or October 30 when the DO peaks were observed. Strong winds, however, were previously experienced on the October 8 and 16 sampling dates. Table XIX (Appendix B) shows that the reservoir was well mixed vertically as early as September 15, and on November 19 good mixing and high (9(+) mg/ℓ) DO characterized the impounded water.

From the evidence it must be concluded that the reservoir was well mixed on October 30, hence both surface and discharged samples would be similar in DO, but that values appreciably above saturation (≃ 9 mg/ℓ) are unexplainable in any manner other than some malfunction in the analytical procedure.

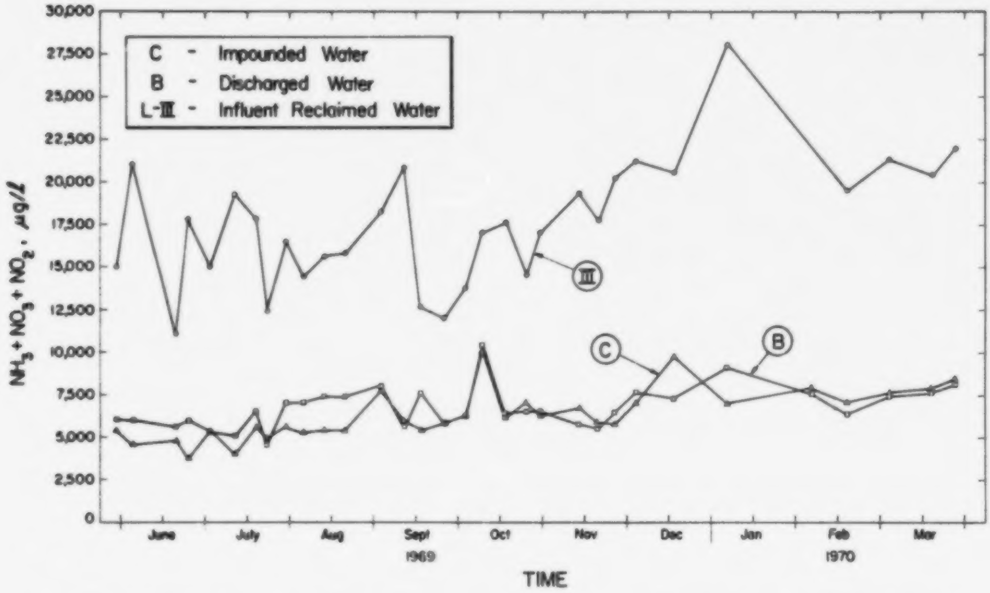

FIGURE 27. VARIATION IN CONCENTRATION OF COMBINED NH_3, NO_3, & NO_2, INDIAN CREEK RESERVOIR

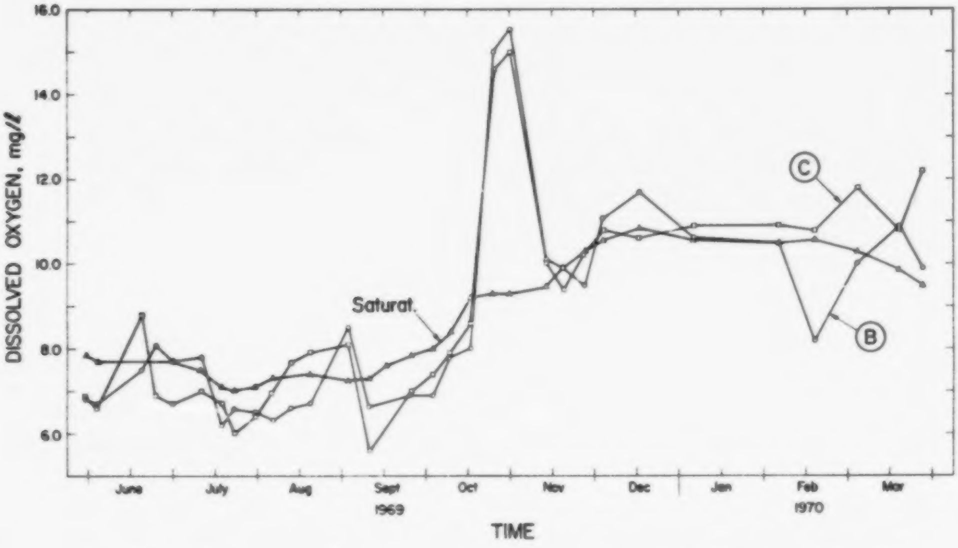

FIGURE 28. VARIATION IN DISSOLVED OXYGEN, INDIAN CREEK RESERVOIR

Vertical and Horizontal Distribution of Quality Factors

1. Oxygen and Inorganic Carbon

The oxygen resources of Indian Creek Reservoir are most clearly evident in the results of 24-hr sampling at approximately bimonthly intervals. This program of sampling was initiated in July 1969. Thereafter similar observations were made in September and November 1969, and in February and March 1970. The results are tabulated in Appendix B along with those of the weekly sampling program. At each of these sampling stations (Figure 6, Chapter III) samples were collected at various water depths at intervals, beginning in late morning on one day and ending on the following morning. In both the November and February periods the sampling program was limited in scope by inclement weather.

Appendix B summarizes data on dissolved oxygen, inorganic carbon, temperature, pH, and alkalinity for various water depths and sampling stations for the following dates: July 16-17; September 15-16; and November 19, 1969, and February 1970. Table XIX (Appendix B) shows that at all stations in July there was a decline in temperature, pH, and dissolved oxygen with depth below the water surface; and an increase in alkalinity and inorganic carbon. The most drastic of these changes was in the dissolved oxygen content.

Figure 29 shows a dissolved oxygen profile at Station 1, the deepest of the three locations (Stations) sampled. It shows that throughout the 24-hr period the DO in the top one-half meter varied from 7.6 to 6.4 mg/ℓ, while at 14 meters (one-half meter above the bottom) the variation was from a high of 0.6 mg/ℓ to a low of 0 mg/ℓ. A similar pattern is shown for Stations 2 and 3 (Table XIX, Appendix B), thus justifying the conclusion that Indian Creek Reservoir was not a well mixed body of water in July 1969.

On the September 15-16, 1969 sampling date temperature, pH, alkalinity, DO, and inorganic carbon showed almost no change from the top stratum down to 9.5 meters. Between 9.5 and 12.0 meters there was a slight drop in temperature and a small poorly defined increase in inorganic carbon. At Station 1 the DO varied throughout the 24-hr day from 5.3 to 4.6 mg/ℓ in the top 0.5 meter, and from 5.4 to 2.9 mg/ℓ at the 12 meter level. Again this same pattern was repeated at Stations 2 and 3. In contrast with the July findings, the September dissolved oxygen profile showed a vertically and horizontally well mixed water mass, with a reduction of oxygen in the upper strata as a result of mixing with the underlying oxygen-poor waters.

By mid-November 1969 all quality factors reported in Appendix B were essentially uniform from surface to bottom of the reservoir. Only one midday sampling was made at the three stations which shows that the DO ranged from 8.6 to 9.6 mg/ℓ in the entire water mass sampled. The table also shows that this same well mixed condition continued in February, although by that time the DO content had risen to 11 ± mg/ℓ.

Table X summarizes from Appendix B the horizontal and vertical distribution of oxygen at midday, mid to late afternoon, and midnight for conditions of diverse and uniform oxygen profile. Although there were some instances of horizontal nonuniformity of oxygen content, of which the midday observation in the 4-5 in. depth range on July 15 is the most striking example, the table shows good agreement from station to station under both unmixed and mixed conditions. Therefore, it is concluded that the Station 1 data (sample C) provides a reasonable basis for computing the oxygen resources of the surface water mass at Indian Creek Reservoir.

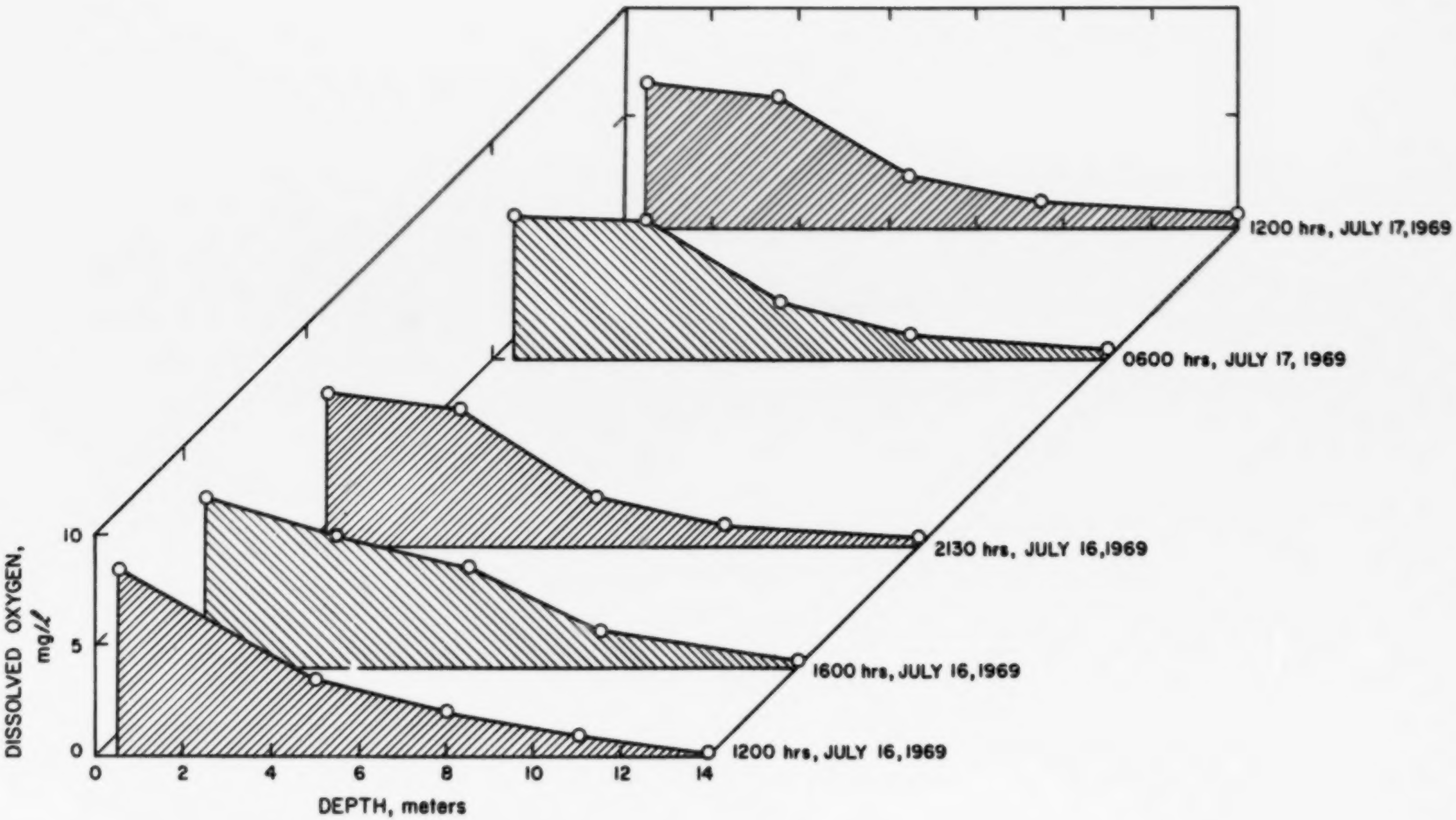

FIGURE 29. DISSOLVED OXYGEN PROFILE AT STATION 1, JULY 15-16, 1969

TABLE X

HORIZONTAL AND VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN IN MG/ℓ, UNMIXED AND MIXED RESERVOIR CONDITIONS

Time (hours)	Depth of Observation (meters)	July 15-16, 1969			Depth of Observation (meters)	September 16-17, 1969		
		Station 1	Station 2	Station 3		Station 1	Station 2	Station 3
Midday	0.5	6.64	6.40	6.72	0.5	4.6	4.8	4.7
	4-5	2.64	4.16	6.00	3.5	4.6	4.8	4.6
	7-8	1.52	2.00	2.48	6.5	4.4	4.6	4.7
	10-11	0.64	0.56	1.60	8.5-9.5	4.3	4.2	4.2
	14	0.0	(below	bottom)	11-12	3.8	3.8	bottom
Mid to Late Afternoon	0.5	7.6	7.7	7.6	0.5	5.8	4.0	4.9
	3.5	5.8	5.9	6.9	3.5	5.5	5.2	5.1
	6.5	4.6	3.2	2.6	6.5	5.3	4.8	4.7
	8.5-10.5	1.6	1.5	1.3	8.5-9.5	5.1	4.4	3.8
	14	0.3	(below	bottom)	11-12	4.2	3.8	bottom
Midnight	0.5	7.0	6.7	7.3	0.5	5.3	3.8	4.1
	3.5	6.3	6.5	5.4	3.5	4.5	4.6	5.0
	6.5	2.3	2.5	2.6	6.5	5.0	4.9	4.7
	8.5-10.5	1.0	0.4	1.5	8.5-9.5	3.3	4.0	4.1
	14.0	0.3	(below	bottom)	11-12	5.4	5.0	bottom

Median values of DO and inorganic carbon (IC) computed for Indian Creek Reservoir for the four sampling dates noted above are presented in Table XI. They summarize in a general way the history of the impounded water during the period July 1969 to February 1970. The table shows that in July the median oxygen saturation was 71 percent. At that time, as shown in Figure 29, the reservoir was not well mixed as regards dissolved oxygen. The temperature profile, however, shows that the reservoir was not stratified in the normal sense. Several factors contributed to the observed DO profile in the unmixed, unstratified reservoir. First, the influent reclaimed water came in at the bottom of the deepest portion of the reservoir carrying only a small amount of oxygen (1 to 3 mg/ℓ). Although it exerted but very little BOD$_5$, its ammonia content was sufficient to contribute some N-BOD to the impounded water. In addition, some oxygen demand can be shown by findings of the benthic survey [8] to be associated with the approximately 3 in. depth of sludge deposited on the reservoir bottom. The rate of inflow (2+ mgd) undoubtedly produced a slow upwelling and radial surface flow of water carrying ammonia and other nutrients into the upper zone where oxygen-producing, carbon consuming biota are normally found. As noted in discussing Figures 19 and 20, a carbon demand did exist, paralleling closely a corresponding decrease in alkalinity. Thus it is evident that nutrients in the upper stratum of impounded water, where an optimum temperature of 20°C prevailed in July, accounts for an important amount of the oxygen reported in the higher zones of the reservoir. Table XI shows that an estimated 1.53×10^4 kilograms of oxygen was in the reservoir on July 15 along with 7.97×10^4 kilograms of inorganic carbon.

By September 15 the oxygen resource had declined from 5.24 mg/ℓ to 4.68 mg/ℓ (1.53 to 1.20×10^4 kg) and the saturation percentage had dropped from 71 to 61 percent. This represented a substantial loss in oxygen without a proportional loss in reservoir volume. The temperature remained high and favorable for biological activity. A small increase in carbon, however, indicated that the oxygen loss was not associated with a corresponding utilization of carbon, since Figure 20 shows that there was no sudden or profound change in the carbon content of influent reclaimed water during the July to September period. Other events occurring during the period – significant releases of water in August and early September, loss by infiltration, loss by evaporation, and small continuous discharge of water – could have only a small effect on carbon concentration because of these four only evaporation effects such change. Values in Table IV show this to be a relatively minor consideration. The conclusion therefore must be that oxygen was consumed by organisms (benthic and planktonic) not dependent upon transient inorganic carbon for their carbon source. (See "Biological Observations.")

From mid-September until mid-November the volume of impounded water was held relatively constant by a combination of evaporation, infiltration, constant small discharge, and reduced influent flow rate. Figure 20 shows that the carbon content of influent reclaimed water was, however, elevated during that period. Temperature (Figure 8) showed a sharp and steady decline beginning on September 15 and continuing uninterruptedly until the November 19 sampling date when it stood at 6.5°C. In fact, after October 15 the temperature was below 10°C and consequently not conducive to biological activity. At the same time seasonal winds disturbed the impounded water and as shown in Table XIX , Appendix B, brought the DO content up to about 9 mg/ℓ throughout the water mass. The result of these factors in combination was, as summarized in Table XI, an increase in the oxygen resource of the reservoir to 92.5 percent saturation (2.36×10^4 kg) by mid-November.

Surface runoff in excess of the influent reclaimed water in December (Table IV) added some 40 percent to the volume of impounded water during the period November 19 to February 5. At the 3.5°C temperature shown in Table XI, the oxygen resource of the reservoir was more than twice the summer value and stood at more than 100 percent saturation. An increase in carbon resulted from the lack of biological activity and from a long sustained period (Figure 20) of constantly high content of inorganic carbon in the influent reclaimed water.

TABLE XI

SUMMARY OF MEDIAN DISSOLVED OXYGEN AND INORGANIC CARBON RELATIONSHIPS, INDIAN CREEK RESERVOIR

Collection Dates	Dissolved Oxygen, mg/ℓ	Inorganic Carbon, mg/ℓ	Volume, m^3	Percent Saturation (DO)	Temperature °C	Total Dissolved Oxygen in Lake, kg	Total Inorganic Carbon in Lake, kg
1969 7/15	5.24	27.3	2.92×10^6	71	20	1.53×10^4	7.97×10^4
9/15	4.68	31.2	2.64×10^6	61	18	12.0×10^4	8.15×10^4
11/19	9.16	33.8	2.59×10^6	92.5	6.5	2.36×10^4	8.72×10^4
2/5	11.1	31.0	3.52×10^6	104	3.5	3.91×10^4	10.9×10^4

Diurnal changes in mass of dissolved oxygen and inorganic carbon were computed for Indian Creek Reservoir for the July and September sampling dates. The results, presented in Figure 30, show the same phenomena as Table XI even though the necessary assumption that the concentration of oxygen and carbon in the water mass is revealed by the observations at three sampling stations is less valid for a one-day than for a two-month period. In July the increase and decrease in dissolved oxygen in the reservoir during the afternoon and evening hours is associated with a utilization of carbon. In September, however, the oxygen increase did not take place at the expense of carbon, indicating again that photosynthetic phenomena were not the controlling factor at that time.

2. Nutrients and Other Chemical Constituents

Summaries of weekly analyses of quality factors presented in Figures 10 to 27 showed that in essentially all cases the impounded water and the discharged water curves did not differ greatly except when major releases of water temporarily disturbed the equilibrium of the reservoir. Because impounded water was sampled in the top one-half meter and discharged water was drawn from the bottom stratum, this similarity was evidence that at least the conservative water quality factors involved did not vary significantly in vertical distribution at Station 1. However, in the case of nutrients where the difference between influent reclaimed water and the surface (impounded) and bottom (discharged) water was the result of both dilution and biological activity the story of vertical distribution was not so self-evident. Ammonia, for example, entered the reservoir at the bottom at a significantly higher concentration than was observed in the bottom and surface samples. The dissolved oxygen profile shown in Figure 30 and Table X indicates that in July, at least, the greatest utilization of nutrients should have occurred in the top stratum where oxygen-producing photosynthesis is most pronounced. Thus the previously presented findings from analysis of weekly samples and hydrological factors yields presumptive but not conclusive evidence that nutrients and other chemical quality factors were horizontally and vertically distributed throughout the reservoir and defined by the 4-point surface and single-point discharge samples. Table X, and other data presented in Appendix B, support the conclusion that in general the reservoir was characterized horizontally by the water quality at Station 1 (i.e., Sample C, Appendix B – a 4-point composite around Station 1) both at times when DO showed mixing or lack of mixing. To check further both the horizontal and vertical characteristics in relation to the C and B (0.5 meter and discharge) samples, Table XII was prepared from the data presented in Appendix B for bimonthly sampling periods.

Columns 3 and 4 of Table XII show the range of horizontal variation between Stations 1, 2, and 3 for samples composited over 24-hr for all depths at each station. Considering that the data presented are mostly in micrograms per liter units it may be concluded that the variation in concentration of all quality factors reported was quite small throughout the water mass, both horizontally and vertically. This was particularly true of the conservative constituents – chlorides and calcium, but even the nutrients showed little variation.

To separate any vertical from horizontal distribution effects, columns 5 to 10 are tabulated. Here the range of values with depth is generally a little greater than in the water mass as a whole, particularly in the case of nutrients. However, the original data (Appendix B) show no discernible pattern of variation. The greatest variation occurs in the iron concentration which is often quite low. On the September 15-16 and again on February 5, a chloride value is questionable. The September value of 44 mg/ℓ is obviously in error. It is reported in Appendix B as occurring at 0.5 meters at a time when all other values at that depth were in the range of 19.3 to 19.7 mg/ℓ. Moreover, at no time after October 1968 did influent reclaimed water contain more than 31 + mg/ℓ of chlorides. The low value of 15 mg/ℓ on February 5, 1970 is atypical of the water column at that time. Appendix B shows that at 3 meters above this point of sampling the chlorides were 17.8 mg/ℓ, while at 3 meters below, the value was 17.2 mg/ℓ. A narrow range of variation in calcium concentration in both September and February further confirms that chloride data on those two occasions are not overriding evidence of poor vertical mixing.

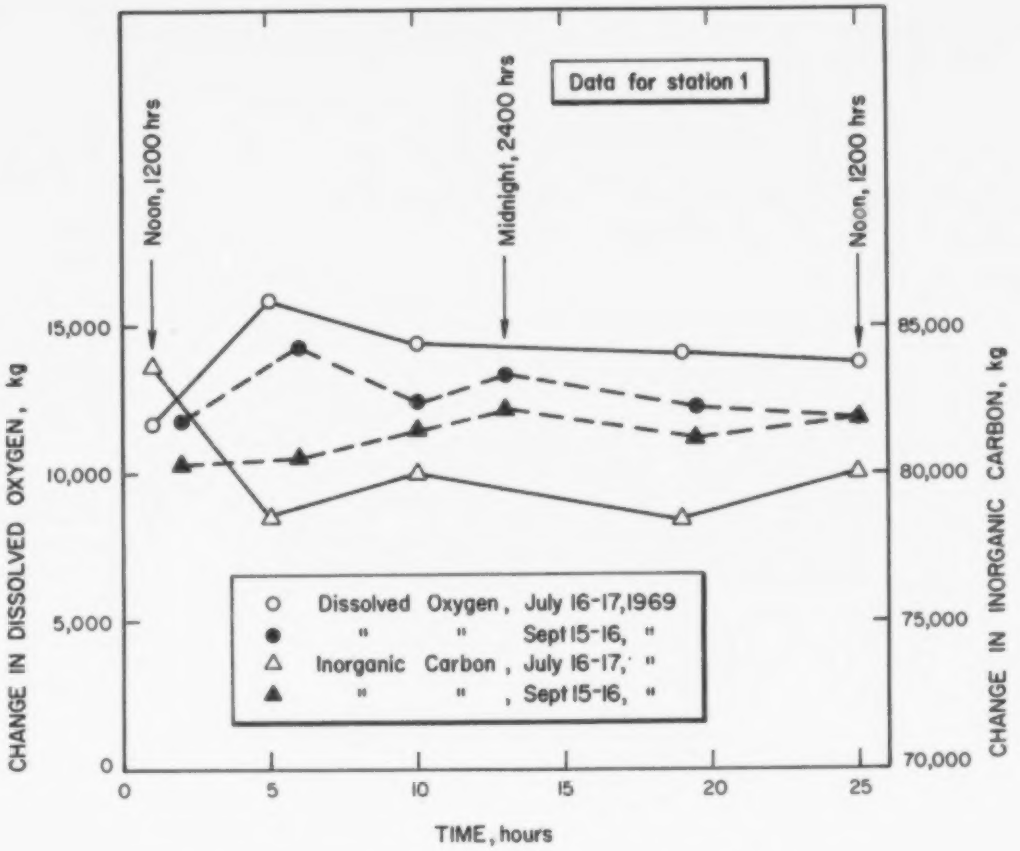

FIGURE 30. CHANGE IN MASS OF DISSOLVED OXYGEN AND INORGANIC CARBON IN INDIAN CREEK RESERVOIR OVER A 24 HOUR PERIOD

TABLE XII

CONCENTRATION OF CHEMICAL CONSTITUENTS SHOWING RANGE OF HORIZONTAL AND VERTICAL VARIATION

1	2	3	4	5	6	7	8	9	10
Quality Factor	Units	Range of Values Between[a] Stations 1, 2, and 3 1969		Range of Values at Different Depths, Stations 1, 2, and 3 1969-1970				Range of Values at Different Depths Mar 18, 1970	
		Jul 16-17	Sep 15-16	Jul 16-17[b]	Sep 15-16[c]	Nov 19[d]	Feb 5[d]	Station 1[e]	Station 2[f]
Unfiltered Samples									
Suspended Solids	mg/ℓ	-	-	-	-	-	-	11.2 - 12.7	9.4 - 12.6
Volatile Suspended Solids	mg/ℓ	-	-	-	-	-	-	9.0 - 10.0	5.3 - 12.6
Organic N	μg/ℓ	-	-	-	-	-	-	1177 - 1416	612 - 1383
Ammonia N	μg/ℓ	-	-	-	-	-	-	3300 - 3470	2680 - 3350
Total P	μg/ℓ	-	-	-	-	-	-	39 - 56	15 - 28
COD	mg/ℓ	-	-	-	-	-	-	15 - 28	18 - 23
Filtered Samples									
Nitrogen	μg/ℓ								
Organic		560 - 810	819 - 905	685 - 885	776 - 1020	292 - 1326	632 - 756	1000 - 1154	1000 - 1192
Ammonia		4525 - 4700	3015 - 3155	3850 - 5300	2490 - 3470	2680 - 3110	4065 - 4530	3060 - 4140	3060 - 4115
Nitrite		19 - 21	250 - 312	20 - 23	250 - 350	155 - 161	130 - 160	66 - 77	65 - 76
Nitrate		1820 - 2140	2132 - 2688	1500 - 2138	2130 - 2310	444 - 539	3570 - 4146	3694 - 3783	3764 - 4148
Total		7244 - 7436	6374 - 6920	6695 - 8065	6246 - 7050	3582 - 4959	8541 - 9272	7988 - 9106	8120 - 9147
Phosphorus	μg/ℓ								
Orthophosphate		33 - 86	45 - 47	16 - 121	40 - 51	48 - 50	53 - 92	6 - 7	4 - 6
Total		92 - 125	66 - 69	47 - 150	57 - 71	58 - 67	61 - 101	19 - 26	15 - 17
Calcium	mg/ℓ	34 - 36	39 - 40	33 - 37	40 - 41	49 - 51	45 - 47	49 - 52	49
Chloride	mg/ℓ	19 - 21	19 - 20	20 - 22	21 - 44	26 - 27	15 - 23	18 - 21	22 - 23
Iron	μg/ℓ	32 - 47	22 - 37	34 - 55	22 - 36	9 - 19	5 - 10	< 1 - 4	< 1 - 11
pH		8.3	7.8 - 7.9	7.8 - 8.3	7.8	7.9 - 8.0	8.0	8.3 - 8.4	8.3 - 8.4
Alkalinity	mg/ℓ as CaCO$_3$	110 - 112	125 - 127	111 - 121	125 - 126	130 - 138	126 - 127	134 - 135	133 - 134
Conductivity	(10^{-6}) mhos	288 - 295	291 - 292	320 - 333	323 - 500	-	382 - 400	340 - 380	350 - 410

NOTE: Dashes indicate no sample analysis.

[a] Samples composited over 24-hr period from all depths for each station.

[b] 0.5 m, 3.5 m, 6.5 m depths and 0.5 m above the bottom. Composited from three stations (1, 2, 3) over 24-hr period.

[c] 0.5 m, 3.5 m, 6.5 m depths. Composited from three stations (1, 2, 3) over 24-hr period.

[d] Single sample from one station 0.5 m, 3.5 m, 6.5 m, and 9.5 m depths.

[e] Single samples from 0.5 m, 6.5 m, 15 m depths.

[f] Single samples from 0.5 m, 3.5 m, 6.5 m, 10 m depths.

From the evidence presented in Table XII it may be concluded that the relatively constant nature of influent reclaimed water appears as an even more constant concentration of nutrients and other chemical factors in the impounded water mass; and that Indian Creek Reservoir water was quite homogenous in nature during the period of observation as regards the factors presented in the table. In the case of oxygen concentration, which is associated with the reduction of influent nutrients (including carbon) to the levels observed in the water mass, a definite oxygen profile existed before physical mixing of the reservoir occurred. Because other soluble components were already dispersed throughout the water mass their concentration was little affected by the physical mixing previously shown to have occurred between July and September 1969, and which continued thereafter. This leads to the further conclusion that as long as the reservoir continues its presently observed behavior there is no reason to extend the scale of the sampling program. But by no means should it be reduced. Although, in a fully mixed water mass a single sample taken at random from any point or at any depth could theoretically reveal the characteristics of the whole mass, with the exception of DO, it is not yet known how further maturing of the reservoir and more frequent periods of water release might affect the uniformity of its quality. It therefore seems prudent to continue the ongoing sampling program.

The foregoing judgment is further documented by data presented in Columns 9 and 10 of Table XII. On March 18, 1970 the vertical profile sampling program was expanded to include particulate as well as dissolved constituents. Suspended solids, volatile suspended solids, and COD all showed, as might be expected, a slight but regular increase with depth; approximately 1 to 10 percent per meter.

One further reason for good coverage of the reservoir surface in any sampling program is that the shallow areas, in which much of the primary production of periphyton and vascular plants takes place, might show a substantial and limnologically significant variation in horizontal and vertical distribution of quality factors and yet have little effect upon the results of a mass balance. Further evaluation of this aspect may be made in relation to the limnological observations at Indian Creek Reservoir.

BIOLOGICAL OBSERVATIONS

Scope of Biological Data

Biological data collected on Indian Creek Reservoir range from general observations of an environmental nature made in the field, to detailed scientific analyses made in the laboratory. The first category includes such aspects as fish and wildlife of the reservoir and immediate area, qualitative observations of algae and rooted plants in the reservoir, and seasonal changes in obvious biota. The more scientific examinations included bioassays of the growth stimulating potential of influent, impounded, and discharged waters of the reservoir, by methods outlined in Chapter III; a benthic invertebrate survey in October 1969; and a plankton analysis in April 1969. Basically the bioassays serve, within the limits of the methods available and of the project finances, to assess the eutrophication potential of water reclaimed from domestic sewage [1] by the most advanced of currently developing technology. The less intensive program of field and biological examinations serve as checks on the validity of any conclusions which might logically be derived from chemical analyses and bioassays of the water.

General Environmental Observations

As shown in Figure 2, Indian Creek Reservoir is located in relatively open country with pinon pine and scrub brush on the east and north. Near the south end, but some hundreds of feet from the shore line, there are larger pines. These occur in a sparse stand at the southwest, with a fairly dense growth on the west at the saddle dam and Stevens Lake. Stevens Lake is shallow and contains a heavy growth of aquatic plants (*Myriophyllum* sp.) which may be expected to be transplanted in Indian Creek Reservoir by waterfowl which frequent the area.

The history of fish plants in the reservoir reveals much information concerning maturing of the reservoir with time. During the summer of 1968 trout were placed in test boxes in the reservoir but died within a period of 30 minutes to 24 hours. To test the reservoir environment further 2080 rainbow trout fingerlings 3 in. to 4 in. long were planted in the reservoir on October 16, 1968, some 6 months after filling of the reservoir began. No mortality was observed during the fall months but by springtime no fish remained. Fish mortality, however, seems due to a prolonged heavy ice cover of the water surface during the winter of 1968-1969.

On August 8, 1969, 3600 hybrid (rainbow and cut throat) trout 1.7 in. in length were planted in the reservoir. Three days later 4400 trout of the Hat Creek (Mono County) Rainbow strain were planted. These were some 4-1/2 in. in length. An overnight gill netting operation in October 1969 produced a catch of 130 of these fish. By this time the 1.7 in. fingerlings had grown to 6 in. in length; and the 4.5 in. group now averaged 8.9 in. long. Subsequently, in March 1970, a one-day gill net setting yielded 18 fish most of which were 11 in. long, the smallest being 10 in. On February 20, 26, and 27 a total of 31,000 rainbow trout of the Mt. Whitney strain (4-1/2 in. to 6 in. long) were planted in the reservoir.

Obviously something occurred during the reservoir's development which made it compatible to trout. Although the exact cause of mortality of fish in the 1968 tests is not known, some toxic factor was evidently present. Inasmuch as ammonia at a concentration of about 2.5 mg/ℓ is reported to be lethal to trout it seems the most logical suspect. This is supported by the fact that in recent (1970) experiments trout were successfully maintained in test aquarium containing tertiary effluent with less than 1 mg/ℓ NH_3-N. In contrast, Appendix A and Appendix C show that the influent to the reservoir (L-III) contained ammonia in concentrations of 12 to 20 mg/ℓ. However, in the reservoir water (C) the concentration ranged from about 2.5 to 5 mg/ℓ, averaging about 4 mg/ℓ. As previously noted, dilution alone did not account for the reduction in ammonia. Instead it results from the biological activity in the water and benthos of the reservoir. Assuming that ammonia is the toxic factor in the water, two conclusions are supported by the experience with fish life in Indian Creek Reservoir:

1. That the establishment of a balanced ecosystem capable of limiting the ammonia concentration was necessary before the water became a suitable environment for trout.

2. Some trout, especially those of the species and strains introduced to Indian Creek Reservoir, can thrive at concentrations of ammonia double that normally thought to be limiting.

Of course, the factors involved in fish mortality and survival in Indian Creek Reservoir are likely to be vastly more complex and subtle than the simple factor of ammonia. Continued observation of the reservoir may lead to more certain conclusions than the foregoing.

Soon after the introduction of trout, grebes were observed on the water. In September the waterfowl count included more than 10 grebes, a similar number of coot; 12 ducks; a small seagull; and a flock of sandpiper. Other wildlife included frogs and snakes; and some 50 Brewer blackbirds were resident in the area. On October 24, 1969 50 ducks were present and in mid-November the duck population was estimated at 150. By late November all ducks had disappeared, no wildlife was observed in early January. Deer were numerous in the area by mid-February and by mid-March ducks had returned, 40 being counted on the March 18, 1970 sampling date. Fish netted in March were 11 in. in length, well fed, and weighed from 2/3 to 3/4 of a pound each. On April 23, 1970 5 deer and two coyotes were observed in the area. Ducks were present on both Steven's Lake and Indian Creek Reservoir.

Aquatic plants in the lake were profuse and muddied water and snail shell fragments give evidence of ducks feeding in the shallows. At about this same time 30,000 rainbow trout fingerlings were introduced into the reservoir.

Gross observations were made of the insect, plant, and plankton life in the reservoir on weekly sampling dates. Throughout the summer and fall of 1969 twigs and stores in the shallow waters were covered with attached filamentous algae (Mougeotia). This disappeared during the winter and was nowhere in evidence on April 23, 1970. However, at that time the early spring cold water alga, Ulothrix, was in evidence and growing in profusion in Indian Creek just below the outlet to the reservoir. In July 1969 midges (Diptera) were observed in flight and resting on the surface of shallow water. Daphnia were found at all sampling stations in the reservoir and were observed to decrease with depth, the density (number per liter) varying directly with dissolved oxygen concentration. In late July a profuse growth of filamentous green algae (Draparnaldia) was present on the buoy and anchor rope at Station 1 (Figure 6, Chapter III). On September 10, 1969 this same alga appeared on the buoy anchor rope at Station 3, extending down to a depth of 6 meters. At Station 1 the filaments were less noticeable. On September 15 Daphnia were present in all water samples taken at all three sampling stations. Few macroorganisms were observed in benthic mud samples. Rooted aquatic plants, predominantly Potomageton, were found in profusion off the point of land between the main and saddle dams. Eel grass and other aquatic plants were present in the shallow south bays of the reservoir. Filamentous green algae Prasiola appeared, floating on the water surface in small clumps. Ten days later it was still present. In early December Indian Creek near the reservoir outlet was exceedingly green. In March 1970 the reservoir was likewise green in appearance. On April 23, 1970 green masses of algae in Indian Creek below the reservoir were observed to be, as previously noted a profuse growth of Ulothrix.

Microscopic Examinations

Samples of water and benthic muds were taken on several of the sampling occasions cited in the preceding section. These were preserved and later examined under the microscope by Dr. James B. Lackey, along with fresh samples taken on April 23, 1970. The organisms observed by microscopic surveys are summarized in Tables XIII and XIV (see [19,20]).

From the survey of preserved samples reported in Table XIII it is evident that a varied plankton population, indicating good productivity, had developed in Indian Creek Reservoir by July 1969. Both green and blue-green algal forms were present as were diatoms and anchored plants. Protozoa were present at the benthic interface. The presence of ammonia in the influent reclaimed water would lead one to expect a diverse plankton population. Similarly, the reduction in ammonia and carbon, discussed in a preceding section, is in itself evidence of an active biota in the reservoir. These findings support the conclusion that a maturing of the reservoir was a necessary prelude to fish survival, not only to develop a food source but also to reduce toxicity.

Table XIV, prepared from the results of microscopic examination of fresh samples of water and benthic muds, is much more revealing of the productivity of Indian Creek Reservoir than is Table XIII. The variety and amount of planktonic biota shows the reservoir to be a highly productive body of water. In fact the sample described as "Floating Floc — Lake Debris" shows a spectrum of organisms typical of impounded water, which indeed characterized the reservoir in April 1970 as a result of no releases after September 1969; and the diversion of influent in March 1970 when the reservoir reached full capacity.

TABLE XIII

RESULTS OF MICROSCOPIC EXAMINATION OF PRESERVED SAMPLES, INDIAN CREEK RESERVOIR

Sampling Date: July 29, 1969	
Profuse filamentous material on buoy and anchor rope at Sampling Station #1.	
Chlorophyta Draparnaldia	
Sampling Date: September 10, 1969	
Material on buoy anchor rope at Sampling Station #1. Heavy growth to six meters depth.	Material on buoy anchor rope at Sampling Station #5.
Bacterial slime (heavy growth) Chlorophyta Cosmarium (Desmid) Capsalated alga (unitentified) Diatoms Navicula	Chlorophyta Draparnaldia Cosmarium (Desmid) Closterium (Desmid) Cyanophyta Merismopedia Lyngbya Chrysophyta (Diatoms) Navicula (numerous)
Sampling Date: September 15, 1969	
Algae attached to dead sedge at point between main dam and saddle dam.	Live vascular plant. Heavy growth in one to two ft of water off point of land between main and saddle dams.
Chlorophyta Draparnaldia (dominant) Cyanophyta Schizophrix (dominant) Chrysophyta Epiphytic algae	Potomageton
Floating green algae collected from lake surface near east shore and main dam.	Algal growth on live Eel Grass from one to two ft of water off land point between main and saddle dams.
Chlorophyta Prasiola	Chrysophyta Network of Epiphytic algae Chlorophyta Chlorella (very numerous) Cosmarium (Desmid) Draparnaldia
Benthic sample taken by dredge in 15-meter depth of water at Sampling Station #1. (Subsurface mud mixed with sample; preservation not good.)	Benthic sample by dredge at Sampling Station #2. Water depth, 12 m. (Subsurface mud mixed with sample,, preservation not good.)
Chrysophyta Navicula (Diatom) Euglenophyta Euglena sp.	Chrysophyta Navicula (Diatom) Pine pollen Note: Very little to see in sample.
Benthic sample by dredge at Sampling Station #5. Water depth 9.5 m.	Benthic interface in 5-cm water depth at main dam near Indian Creek channel.
Chrysophyta Navicula (Diatom) Note: No other organism observed in sample.	Chlorophyta Cosmarium (Desmid) Chrysophyta Navicula (Diatom) Cyanophyta Schizothrix Ciliate Protozoa Colpoda
Benthic interface in 5-cm water depth at boat launching ramp (east side of reservoir approximately 300 ft south of main dam).	Benthic interface in 5-cm water depth at south end of small embayment on east shore of reservoir.
Chlorophyta Closterium (Desmid) Chrysophyta Navicula (Diatom) (very numerous) Ciliate Protozoa Pleuronema	Chrysophyta Navicula (Diatom) (numerous) Cyanophyta Merismopedia Schizothrix Lyngbya Chlorophyta Cosmarium (Desmid) Ciliate Protozoa Colpoda
Sampling Date: March 18, 1970	
Surface tow with plankton net between main dam and Sampling Station #2.	Outlet from Indian Creek Reservoir. Filamentous bloom at time of sampling. Sample unpreserved.
Daphnia Rotifers Harpacticoid Copepod Worm	Chlorophyta (Filaments too decayed for positive species identification.) Cosmarium (Desmid) Ciliate Protozoa Paramecium Cyclidium

TABLE XIV

RESULTS OF MICROSCOPIC EXAMINATION OF FRESH SAMPLES, INDIAN CREEK RESERVOIR, APRIL 23, 1970

Water Sample, Station #1 (centrifuged)	Water Sample, Station #2 (centrifuged)	Water Sample, Station #3 (centrifuged)
Chlorophyta Green algal cells (unidentified) Cosmarium (Desmid) Chrysophyta Navicula (Diatoms) Meridion (Diatoms) Protozoa Zooflagellates	Chlorophyta Chlamydomonas Cosmarium (Desmid) Chrysophyta Navicula (Diatom) Flagellate Protozoa Zooflagellates Miscellaneous Hillea	Chlorophyta Cosmarium (Desmid) Cryptomonadidae Cryptomonas Chrysophyta Navicula (Diatom) Euglenophyta Euglena Flagellate Protozoa Zooflagellates
Water Sample, South Embayment (centrifuged)	Station #1, Bottom (centrifuged)	Lake Plankton, Including Small Amount of Bottom Sediment
Chlorophyta Chlamydomonas Cosmarium (Desmid) Chrysophyta Navicula (Diatom) Flagellate Protozoa Zooflagellates Ciliate Protozoa Lionotus fasciola	Chlorophyta Chlorella Flagellate Protozoa Anisonema ovale Monas Bodo Zooflagellates Ciliate Protozoa Cyclidium Miscellaneous Cladocera ephippia	Chlorophyta Cosmarium (Desmid) Mougeotia Cryptomonadidae Cryptomonas Chrysophyta (Diatoms) Navicula Gomphonema Synedra capitata Asterionella formosa Flagellate Protozoa Zooflagellates
Floating Floc – Lake Debris	Reservoir – Lake Debris	Growth on Buoy, Sampling Station #2
Chlorophyta Cosmarium (Desmid) Closterium Evastrum Cryptomonadidae Cryptomonas Chrysophyta Navicula (Diatom) Cyanophyta Oscillatoria Schizothrix Euglenophyte Euglena Flagellate Protozoa Bodo Chroomonas Notoseenas apocamptus Peranema Ciliate Protozoa Oxytricha Cinetochilum Aspidisca castata Chilodonella Stichotricha Miscellaneous Rotifer Dipterous larvae	Chlorophyta Cosmarium (Desmid)(vast amount) Chlamydomonas Ciliate Protozoa Cyclidium Oxytricha Flagellate Protozoa Notoselenas apocamptus Zooflagellates (vast number) Cryptomonas Chroomonas Chrysophyta Navicula (vast number) Miscellaneous Amoeba vespertilio Rotifer	Chlorophyta Cosmarium Closterium Chlamydomonas Chlorella Ulothrix Cyanophyta Oscillatoria Lyngbya Schizothrix Chrysophyta (Diatoms) Navicula Eunotia Chryptomonadidae Chryptomonas
Floating Floc Oppostie East Boat Launching Ramp	From Concrete Bottom of Outflow from Reservoir	Algal Net (Dense Mat) in Runoff Ditch Below Dam
Chlorophyta Chlorella Cosmarium (Desmid) Closterium Chlamydomonas Chrysophyta Navicula (Diatom) Cyanophyta Merismopedia Oscillatoria Proteomyxa Nuclearia Mycetoza Amoeba Ciliate Protozoa Oxytricha Vorticella Flagellate Protozoa Notoselenus apocamptus Chryptomonadidae Chryptomonas	Chlorophyta Cosmarium (Desmid) Chlorella Closterium Euglenophyta Petalmonas Euglena sp. Euglena gracilis Spenomonas teres Anisonema ovale Chrysophyta Navicula (Diatom) Cryptomonadidae Cryptomonas Mycetoza Amoeba vespertilio Ciliate Protozoa Vorticella Aspidisca costatus Cyclidium Flagellate Protozoa Notoselenus Chroomonas Miscellaneous Nematode Chirinomid larvae Chrinita	Chlorophyta Ulothrix Closterium Cosmarium (Desmid) Scenedesmus Cyanophyta Merismopedia Cryptomonadidae Cryptomonas Euglenophyta Euglena viridis Ciliate Protozoa Oxytricha Cyclidium Miscellaneous Rotifer Chironomid larvae Growth on Dead Grass In Reservoir Chlorophyta Cosmarium (Desmid) Closterium Chlamydomonas Chrysophyta Eunotia Navicula (Diatom) Flagellate Protozoa Notoselenus Chroomonas Ciliate Protozoa Oxytricha Vorticella

As the reservoir is operated more nearly on its design schedule during the 1970 irrigation season it will be both interesting and important to observe the reservoir biota, especially with respect to its response to nutrients as the residence period of water varies. However, it would seem highly unlikely that the relatively long residence time in comparison with the regenerative time of plankton will lead to a drastic alteration of the aquatic environment capable of interfering with its planned operational schedule.

Benthic Organism Survey

A survey of benthic invertebrates was conducted of Indian Creek Reservoir, and of Indian Creek downstream of the reservoir, by Mr. W. Arthur Noble, of the FWQA [8]. A preliminary report of the findings is herein included as Appendix F. Samples of bottom sediments were obtained at seven stations in the reservoir by means of an Ekman Dredge. One sample was obtained by scrubbing rocks, obtained from 2-in. to 2-ft depths at the main dam, in a bucket of water. This same technique was used on rocks taken from the Indian Creek Station. At the time of sampling, October 8-9, 1969, the water depth in the reservoir was 48.75 ft and the deepest points had been under water continuously for some 18 months.

As reported in detail in Appendix F, 17 dredge samples representing 4.25 sq ft of a total lake bottom of 127 acres (5.532×10^6 sq ft) showed a standing crop of midge larvae at an average density of 464/sq ft; not an unusually high number for a lake. Some 98 percent of the midge larvae were of three types – *Chironomus*, *Procladius*, and *Glyptotendipes* – all of which have pigmented gills making possible increased oxygen uptake in poorly oxygenated waters. Apparently there was an oxygen problem in the benthos that restricted the midge population to low oxygen resistant types.

Winter eggs of Cladocera (ephippia) averaged 3,142/sq ft, indicating that a very large population of Cladocera had previously existed during the summer months. This in turn means that an extremely high population of algae, bacteria, and detritus on which Cladocera feed must also have been present.

A low species diversity of midge larvae, the dominant form (85 percent) being the low oxygen tolerant *Glyptotendipes*, was observed in the samples obtained by scrubbing of rocks from the shallows at the dam face. The results from Indian Creek likewise showed a species diversity very low for a stream environment. "Dominance by midges, absence of stoneflies and caddisflies, and the presence of only the pollution tolerant mayfly nymph Siphhonurus," Noble reported "indicates enriched and eutrophic conditions." The presence of a heavy growth of algae likewise gave the appearance of a nutrient rich stream.

The October 8-9, 1969 benthic survey leads to the conclusion than an oxygen shortage existed at the reservoir bottom at that time. No horizontal and vertical oxygen profiles were run in October but Appendix B shows that DO in the surface water at Station 1 (Sample C) on October 8 was 7.9 mg/ℓ. At the same time the discharged water had a DO content of 7.8 mg/ℓ. Data previously presented (Figure 28, and Appendix B) shows that in July 1969 there was indeed an oxygen shortage at 14 meters (1/2 meter above bottom) at Station 1, although the surface water ranged from 7.6 to 6.4 mg/ℓ during the 24-hr period of observation. In mid-September there was evidence of better vertical mixing. At Station 1, DO in the surface stratum varied from 4.6 to 5.8 mg/ℓ, while at the 12 meter depth the DO ranged from 3.8 to 5.4 mg/ℓ during a 24-hr period of sampling. Mixing was especially evident on November 19, when oxygen levels at Station 1 were 8.9 mg/ℓ at the surface and 9.3 mg/ℓ at 12 meters depth.

In December 1969, when ice cover developed, an aeration system was installed in the reservoir to insure adequate mixing to protect the planted fish population. On the basis of only one year of record it cannot be stated with certainty whether the vertical mixing first observed in September was a seasonal phenomena or represented a change in the limnological characteristics of the reservoir as it matured. The reservoir should be monitored carefully in 1970 to observe the benthic biota and the oxygen profile. Presumably artificial mixing will be resorted to if DO levels become critical. Thereafter the midge larvae will presumably no longer serve as a natural indicator organism as in 1969.

Further data of the type herein reported will reveal what further processing of waste water, if any, is necessary to ensure against eutrophication of impounded undiluted reclaimed water; or what management procedures may be appropriate to such impoundments in general, and to Indian Creek Reservoir in particular.

Nutrient Budget

From analytical data presented in Appendices A, B, and D it is clearly evident that the N/P ratio of influent reclaimed water was a very large value, averaging some 150 to 1 during the period April 1969 to March 1970 (see Table XXVII, Appendix D). For the same period the N/P ratio in Indian Creek Reservoir water averaged about 17 to 1, indicating that even after some considerable reduction in soluble nitrogen, the Indian Creek Reservoir water was still phosphorus limited as a substrate for algal growth. However, as discussed in relation to the fish resource and the benthic survey of the reservoir, a considerable biota flourished in the water once the reservoir had matured to some degree. In the case of trout, evidence was presented to support the conclusion that a very large reduction in the concentration of ammonia (from 15 to about 4 mg/ℓ) led to the development of an environment in which the fish could prosper. In the absence of a favorable supply of phosphorus it seems unlikely that aerobic aquatic life could have accomplished the changes in nitrogen concentration reported in Appendix D to be as shown in Table XV:

TABLE XV

SUMMARY OF CHANGES IN NUTRIENT CONCENTRATION – INDIAN CREEK RESERVOIR
(April 1969 to March 1970)

Sample	Mean Concentration of Nutrients (μg/ℓ)				
	NH_3-N	(NO_2 + NO_3)-N	Total-N	PO_4-P	Total-P
Influent (L-III)	17,942	164	19,313	126	148
Indian Creek Reservoir (C)	4,006	2,728	7,717	67	87

Assuming that nitrogen and phosphorus are utilized by aquatic organisms in a ratio of 10 to 1, the observed reduction in PO_4-P could have tied up but 600 μg/ℓ of nitrogen. Another 2,564 μg/ℓ of NH_3-N appeared as an increase in (NO_2 + NO_3)-N, thus accounting for about 3,100 μg/ℓ of a total reduction in NH_3-N of some 13,900 μg/ℓ, or of some 11,600 μg/ℓ loss in Total-N.

To identify further the nitrogen loss, an attempt was made to compute a nutrient budget for the entire reservoir based on inputs, releases, concentrations, etc., previously presented in Table IV and in Appendices B, C, and D. For an 11-month period the net input of soluble nitrogen was computed at 136,000 pounds, resulting in a soluble nitrogen increase to about 40,000 pounds by March 1970. Thus some 96,000 pounds of nitrogen were lost out of solution. Two possibilities, either singly or in combination, may account for this finding. Nitrogen may have been:

1. Converted to volatile solids by living cells, provided a source of phosphorus existed, or

2. Lost from the system as gaseous nitrogen or as ammonia.

Because of the low concentration (0.01 to 0.17 mg/ℓ), less impressive values appeared for phosphorus. Only about 560 net pounds of P reached the reservoir from all influent sources during the year. The resulting concentration of phosphorus in the reservoir water fluctuated between 0.02 and 0.08 mg/ℓ but the net change for the year appeared to be insignificant. Again it is evident that the water borne influent phosphorus cannot account for the utilization of nitrogen in the amounts observed.

Just how much phosphorus may have been available in the soil when the reservoir was created remains an unknown factor. A soil sample composited from 20 locations in the cleared area above the water line in September 1969 showed the following analysis:

Available P	0.01 mg/g
Organic Carbon	0.83%
Inorganic Carbon	0.3%
NO_3-N	0.36 mg/g
NH_3-N	0.029 mg/g
Organic N	0.58 mg/g
Sand	32.5%
Silt	35.5%
Clay	32.0%

The soil from which the above sample was taken had been subjected to one winter's runoff and considerable microvein erosion of the surface was evident at the time of sampling; it may be that the surface was richer in phosphorus at the time the reservoir was first flooded in 1968. However, assuming for the sake of order of magnitude evaluation that 0.01 mg/g was typical of the original soil and that the phosphorus in the top 0.5 cm of soil was available to benthic organisms, the soil might have added as much as 7,500 pounds of phosphorus to the reservoir budget from a surface of 150 acres. Adding to this some input from observed erosion of stripped soil, and taking 10 to 1 as a reasonable N/P ratio for nutrient use by aquatic organisms, such an amount of phosphorus could have supported a biomass capable of tying up temporarily the estimated 96,000 pounds of unaccounted for nitrogen. At 10 percent dry weight as the nitrogen component of algal cells, the total volatile solids in the 2,600 acre-ft of water corresponding to a pond area of 150 acres would have approximated 9.6×10^5 pounds, or about 135 mg/ℓ. If such an amount of volatile solids did indeed exist it was in the benthic deposits, as only 2 to 3 mg/ℓ of VSS appeared in the reservoir water. No analyses of the benthic deposits are available but at sampling stations it was observed to be 2 or 3 centimeters in depth; enough to make 135 mg/ℓ volatile solids a plausible value.

Nevertheless, several facts and reasoned judgments refute the possibility that the nitrogen decrease was due primarily to utilization of nitrogen and phosphorus in the biomass. The following are among the most important:

1. The VSS observed in the water mass was never very high (7+ mg/ℓ, Appendix D).

2. Erosion of the surrounding land area, although bringing in silt which may be presumed to carry absorbed phosphorus, never produced an identifiable increase in the phosphorus content of the water mass. Utilization of benthic phosphorus must therefore have been largely done by benthic organisms and by fish which feed upon them. Based on the benthic survey findings of 464 dipterous larvae per sq ft in October 1969 (Appendix F) and an estimate of nutrients tied up in some

two tons of trout in the reservoir at that time, a rough estimate of nutrients tied up in fish and larvae is 7,300 pounds of nitrogen and 730 pounds of phosphorus – less than eight percent of the missing nitrogen.

3. Midge production by the reservoir, although on occasion prolific, was by visual observation less than adequate to account for more than 6,000 pounds of phosphorus and ten times that amount of nitrogen.

4. It is rationally inconceivable that the water mass could have so circulated as to make its soluble nitrogen available to organic life compelled to utilize phosphorus essentially exclusively in the benthos.

The possibility that nitrogen was lost from the reservoir is the more credible possibility. At the pH range existing in the reservoir (7.2 – 8.2), however, appreciable loss as ammonia is not a reasonable assumption. On the other hand, denitrification is a well documented limnological phenomenon. For example, Brezonik and Lee [21] reported in 1968 denitrification rates in the hypolimnion of Lake Mendota in Wisconsin of 8 to 26 μg N/ℓ/day – about 11 percent of the influent nitrogen. In experimental deep anaerobic ponds designed for nitrogen removal from return waste waters in California [22], 20 to 90 percent loss of nitrogen as gaseous N have been achieved when an appropriate source of carbon (methanol) was supplied. When in the light of such findings it is considered that the dipterous larvae reported in Indian Creek Reservoir in October 1969 were of low-oxygen tolerant species; that anaerobic conditions were known to exist in the benthos at certain seasons during the study; and that a source of both nitrogen and phosphorus for anaerobic organisms existed in the benthos, it must be concluded from the evidence at hand that a nitrogen loss from the reservoir did occur in 1969. However, at the present level of refinement of data it is not possible to make a materials balance for nitrogen which assign reasonably accurate numerical values to the amounts lost by soil infiltration, biological life, gasification, etc. Neither is it possible to say to what degree soluble constituents in the soil contributed to the nutrient budget of the reservoir during 1969-1970. Therefore only the future can reveal what the effect on the biota of Indian Creek Reservoir may be if the influent to the reservoir continues to be phosphorus poor and any existing eutrophication cycle based on utilization of soil nutrients and long residence time is disturbed by the major releases of water which must occur annually in the future operation of the reservoir.

Bioassays

Bioassays of influent reclaimed water, impounded water, and discharged water at Indian Creek Reservoir were made by the flask assay method described in Chapter III. This method was adopted because considerable experience in the technique and interpretation of the test were accrued by the project staff during three years of previous and concurrent study of waters in the Lake Tahoe Basin [2,3,4]; and because the development of standard techniques by the FWQA [23] and its contracting groups have not yet produced a more acceptable alternate procedure. Moreover, the use of a single species of test alga (*Selenastrum capricornutum**, in this case) allows the analysis of a large number of samples in a limited space, yet provides a reasonable estimate of the relative biostimulatory response of different samples.

Results of flask assays of Indian Creek Reservoir waters, undiluted and at various concentrations in filtered Lake Tahoe water are summarized in Table XXXI, Appendix E. From these data three measures of growth response were computed as reported in Table XXXII (Appendix E) – specific growth rate, $\hat{\mu}_0$, cell concentration, $\hat{X}_5$, and cell mass produced during 5 days of growth, SS_5. The value of $\hat{\mu}_0$ was calculated by computer analysis as the maximum slope of the growth curve [3] identified by cell counts after 1, 3, and 5 days of incubation. $\hat{X}_5$ is the maximum number of cells attained at the end of the 5-day growth period, evaluated as the average of replicate counts. SS_5 represents the suspended solids measurement obtained after five days of growth. Because all suspended solids in the assay are cellular material and the accurecy of cell mass estimates by $\hat{X}_5$ counts is dependent upon assumptions of cell size uniformity, SS_5 is herein used, along with $\hat{\mu}_b$, in interpreting the growth stimulating properties of Indian Creek Reservoir waters.

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*[*Selenastrum gracile*](#) prior to July 1969.

As previously noted, and as evident in Table XVIII, Appendix B, the influent reclaimed water entering Indian Creek Reservoir was so overwhelmingly phosphate limited that no biochemical changes during the period of impoundment came within an order of magnitude of bringing N and P into biological balance in either the impounded water or the discharged water during the period of study. Quite likely, as discussed in the preceding section, biological activity in the benthos utilizing phosphorus from the soil, together with denitrification and dilution (approximately 20 percent during May to December 1969) accomplished the observed reductions and conversions in nitrogen compounds necessary to make the reservoir water tenable to trout.

Figure 31, plotted from Table XXXI (Appendix E), shows graphically the variation in specific growth rate, $\hat{\mu}_b$, in comparison with phosphorus concentration in the discharged water (Sample B). Although the data are scattered, they show that regardless of PO_4-P concentration, the growth rate showed little increase above 15 or 20 $\mu g/\ell$-P. This means that in the Indian Creek Reservoir ecosystem, the maximum growth rate in the water was achieved at a relatively low phosphate concentration. In this case $\hat{\mu}_b$ increased only from 0.84 $days^{-1}$ to 0.96 $days^{-1}$ as PO_4-P increased from 16 to 180 $\mu g/\ell$. When $\hat{\mu}_b$ is plotted against inorganic nitrogen concentration (Figure 32) there is a tendency for the same pattern to appear. This undoubtedly means that if phosphorus is indeed the limiting nutrient, as logic and the data suggest, then there is no important relationship between inorganic nitrogen and growth rate unless the nitrogen is present as ammonia at toxic levels — a possibility that cannot be immediately dismissed.

The possibility that some micronutrient or iron may have been the controlling factor and so make Figure 31 meaningless, is rendered unlikely by findings in pond assays at Lake Tahoe [4] in which two percent tertiary effluent in Lake Tahoe water was shown to stimulate the same growth with and without added micronutrients.

When PO_4-P concentration was compared graphically with cell count, $\hat{X}_5$ (figure not shown) there was an extremely wide scatter of data with a general but crudely defined trend toward higher counts with increasing phosphorus, but the pattern was too poor to support any valid conclusion.

To explore further the relationship of growth rate, $\hat{\mu}_b$, to nitrogen and phosphorus a plotting was made of $\hat{\mu}_b$ versus N/P ratio computed both from total inorganic N/PO_4-P and NH_3-N/PO_4-P. The results show growth rates of from 0.07 to 1.50 occurred at N/P ratios of from 19/1 to 100/1 with no detectable pattern. The plot (not herein reproduced) shows clearly that the factor which led to varying growth rates was not revealed by N/P ratios beyond the point where phosphorus is the limiting nutrient.

The growth parameter SS_5 is shown in relation to initial concentrations of Inorganic-N and PO_4-P in Figures 33 and 34, respectively. In spite of a considerable variation in response from sample to sample Figure 33 shows quite clearly that in the impounded water (Sample C) and reservoir discharge water (Sample B) the growth in terms of suspended solids was but little influenced by nitrogen concentration in a range of from 3 to 7 mg/ℓ. Thus the suspicion seems confirmed that the factor which stimulated the observed growth is not plotted in Figure 33. The same may be said of the factor which prevented growth in the influent reclaimed water. Figure 33 shows that growth in the 100 percent concentration of L-III (tertiary effluent) was but little affected by inorganic nitrogen. Figure 34, shows that it was also unconcerned with PO_4-P. In fact the evidence is that in its raw condition the influent reclaimed water delivered to Indian Creek Reservoir is toxic to *Selenastrum* just as it appears to have been to trout. The question of ammonia concentration again must be asked.

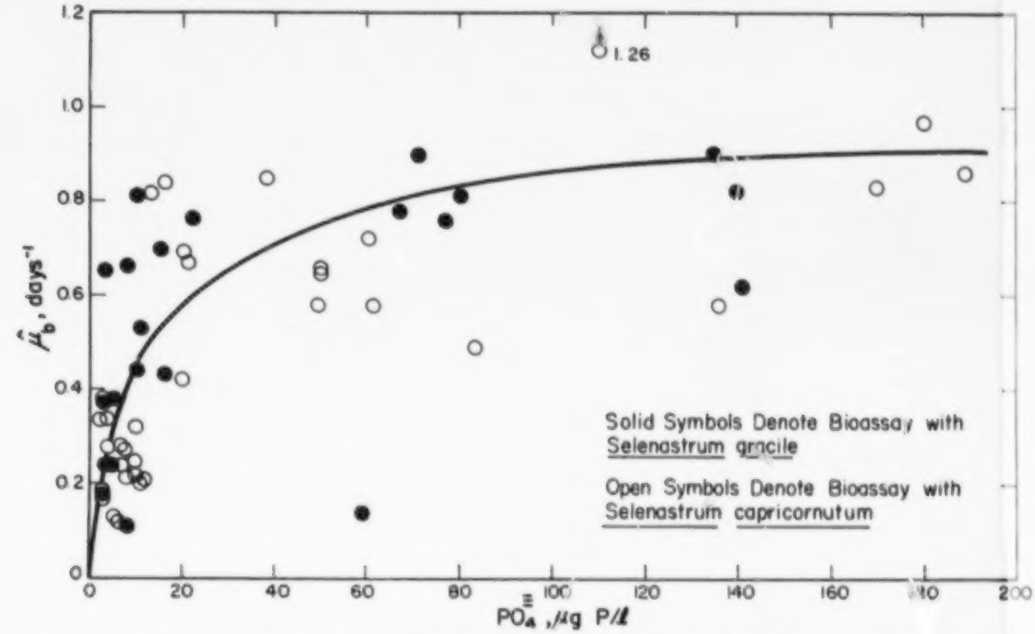

FIGURE 31. VARIATION IN MAXIMUM SPECIFIC GROWTH RATE WITH INITIAL PHOSPHORUS CONCENTRATION FOR DISCHARGE SAMPLES

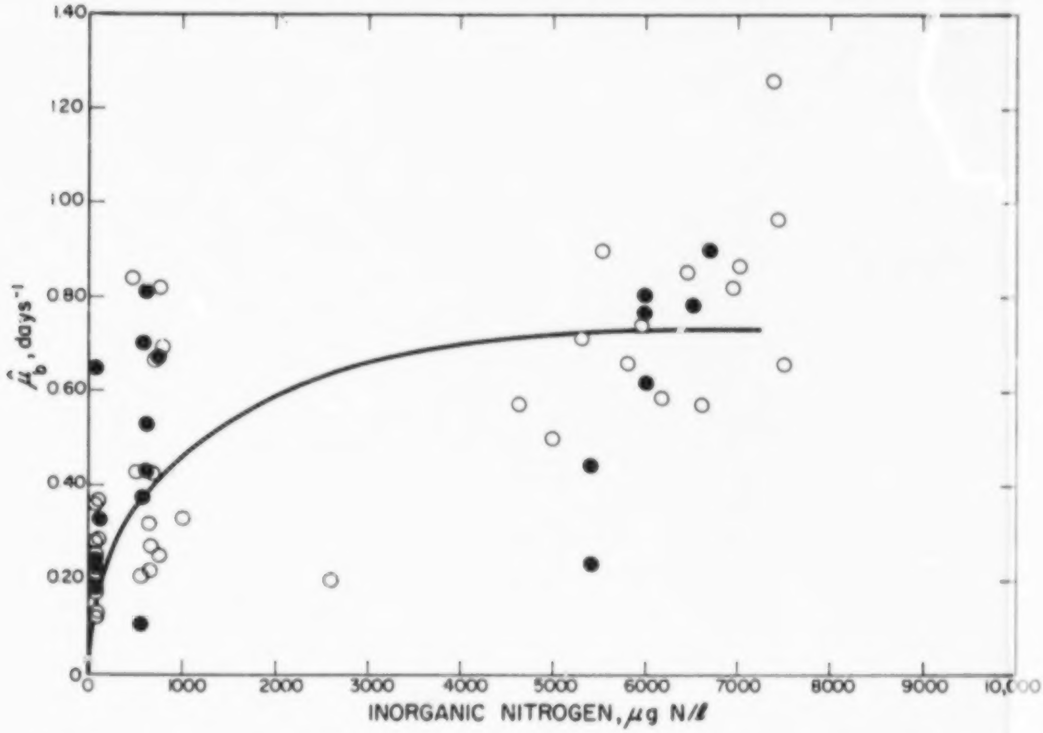

FIGURE 32. VARIATION IN MAXIMUM SPECIFIC GROWTH RATE WITH INITIAL INORGANIC NITROGEN CONCENTRATION FOR DISCHARGE SAMPLES

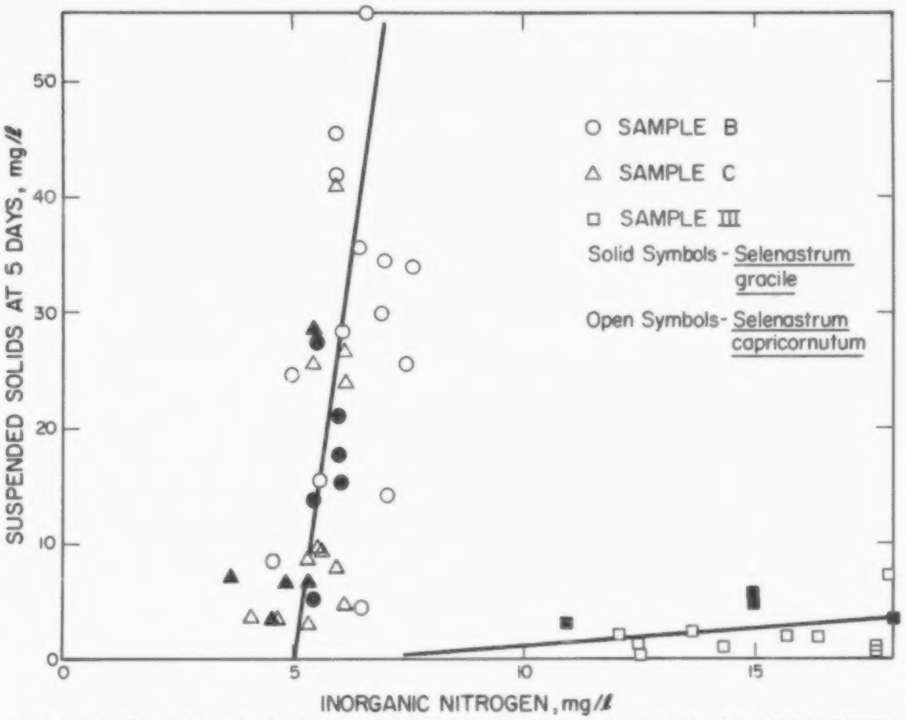

FIGURE 33. FIVE DAY CELL MASS (SS_5) IN BIOASSAYS OF UNDILUTED SAMPLES

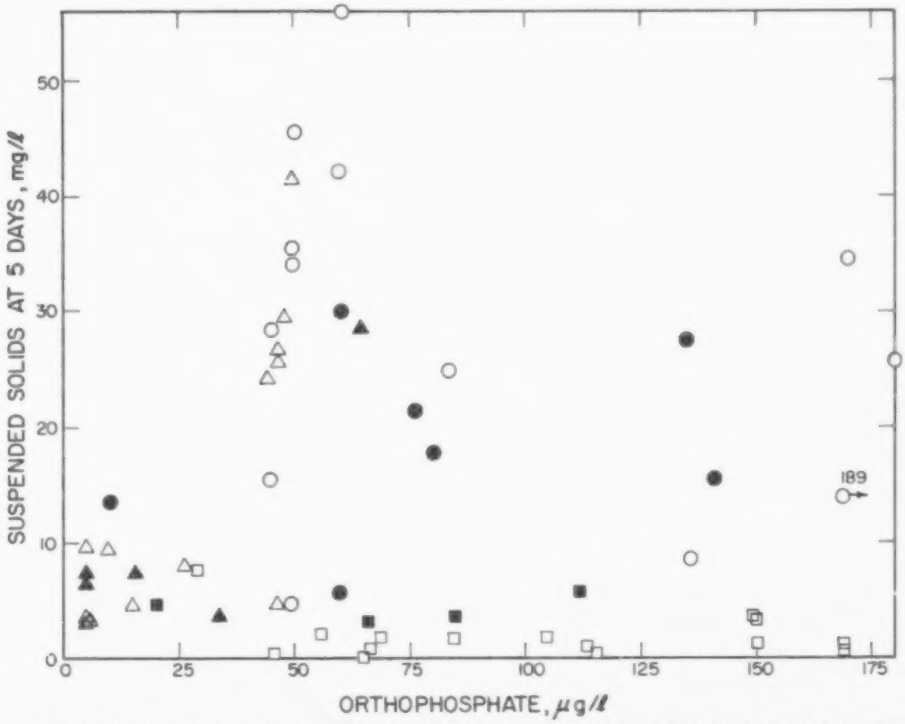

FIGURE 34. FIVE DAY CELL MASS (SS_5) IN BIOASSAYS OF UNDILUTED SAMPLES

As regards the impounded and discharged water, Figure 34 shows that the growth of Selenastrum was somewhat related to phosphate, but the same tendency for a maximum rate to occur that was evident in Figure 31 applied to cell mass as well. That is, in spite of a phosphate limited substrate, Selenastrum did not make full use of such phosphate as became available. Inhibition of growth seems indicated in impounded water, albeit to a vastly less marked degree than in the influent.

To explore the matter of toxicity in inhibiting bioassay response, filtered samples were analyzed at three different concentrations in Lake Tahoe water. Filtered aliquots of water Samples B and C (discharge and impounded water), as well as of Sample L-III (influent reclaimed water) were assayed at concentrations of 100%, 10%, and 1% in Lake Tahoe water collected in the same month. Prior to assay all L-III samples were treated with thiosulfate (~ 2 mg/ℓ) to remove chlorine. Near saturation with DO was restored by shaking the sample. Hence these two factors were eliminated as possible toxicants.

Results of the assays are summarized in Table XVI. They show that the relative suspended solids (Selenastrum) increased with increasing nutrient concentration for B and C samples, but actually decreased slightly for the L-III sample at 100% concentration. However, values for all three samples at the 1% dilution yielded a higher response than observed in baseline Lake Tahoe water (SS_5 = 2.68 ± 1.86 mg/ℓ). From the data obtained in the dilution studies it is clear that dilution overcame the toxic effect to a large degree, although there is no way to determine whether any inhibitory effect remained.

TABLE XVI

RELATIVE VALUES OF RESPONSE (SS_5) AND NUTRIENT CONCENTRATION (S_o) IN ASSAYS OF INDIAN CREEK RESERVOIR WATER[a]

Sample	Concentration of Sample	Relative Suspended Solids (SS_5)	Relative Inorganic Nitrogen (S_o)	Relative Orthophosphate Phosphorus (S_o)
LTW		(2.68)		
B	1.0%	1.00 (3.86)[b]	1.00 (81)	1.00 (4)
	10.0%	1.94 ± 0.887[c]	7.46 ± 2.93	3.00 ± 1.72
	100.0%	7.59 ± 6.82	72.3 ± 9.08	22.3 ± 17.6
C	1.0%	1.00 (3.52)	1.00 (80)	1.00 (4)
	10.0%	1.62 ± 0.636	7.30 ± 0.800	1.68 ± 1.09
	100.0%	5.30 ± 5.59	70.2 ± 8.87	8.98 ± 12.2
L-III	1.0%	1.00 (4.00)	1.00 (189)	1.00 (5)
	10.0%	1.16 ± 0.800	7.95 ± 2.65	3.06 ± 2.03
	100.0%	0.998 ± 1.80	78.5 ± 26.3	24.1 ± 20.8

[a] Relative value determined by relating the response and nutrient concentration at 10% and 100% levels to the 1% level.

[b] Actual measurement of SS_5 (mg/ℓ) and S_o (μg/ℓ) for 1% samples in parentheses.

[c] Mean ± standard deviation.

Seasonal Variation in Assay Results

The results of bioassays of undiluted water samples, B, C, and L-III, are shown in Figures 35 and 36. Considerable variation in values of $\hat{\mu}_b$ is evident in the results summarized in Figure 35. Although the results for impounded water (C) and discharged water (B) are generally quite similar, the influent reclaimed water (L-III) samples show little relation to the others. Some growth was observed for all L-III samples, but the lowest value of $\hat{\mu}_b$, reported on July 22, 1969, was only 0.01 days^{-1}; and the other values were considerably lower than might be expected from the nutrient level. The high response level in mid-August for the B sample (discharged water) may have been influenced by the considerable release of irrigation water from the reservoir just prior to the sampling date. Abnormal values of chemical factors have already been noted as occurring at the time and there is no reason to expect that bioassays would not also reflect the disturbance of existing equilibria. On the other hand, the high value of growth rate in mid-August was the culmination of a pattern of response in Sample B which had risen steadily from July onward.

In general the chemical analyses of samples of impounded (C) and discharged water (B) presented earlier in this chapter indicated that these two waters were quite similar in quality. Such a similarity, however, is not borne out by observations of biostimulatory response during the summer months. The reason is undoubtedly that the impounded water was sampled at the surface, whereas the discharged water sample came from a deeper stratum of the water. Circumstantial evidence presented in relation to the Nutrient Budget indicate that the reservoir bottom was biologically active and dependent upon conditions not characteristic of the water mass. It may well be that the benthos served as a reservoir for trace nutrients which were not detected by the analyses herein reported, whereas the top stratum of water, being the zone of most active plankton growth, had been stripped of such nutrients. Such a situation was observed to exist in pilot ponds at Lake Tahoe [4] where flask assays of the pond effluent showed that the growth which had occurred in the pond had tied up nutrients in algal cells and a false conclusion concerning eutrophication of the pond could easily have been made by the unwary observer. In any event, as described in a previous discussion of Dissolved Oxygen, the summer of 1969 was a period when the benthic zone of the reservoir was very low in oxygen and bacterial activity was undoubtedly releasing nutrients not necessarily available at the water surface.

The general pattern of biostimulatory response in the impounded water, as revealed by Sample C (Figure 35), indicates that there was relatively high stimulation in April and May, followed by a decrease during the summer months. A second period of productivity occurred in late fall but by December the temperatures were too low for continued high rates of growth. This pattern is readily explainable in the light of environmental factors not revealed by the assays themselves. Ice cover on Indian Creek Reservoir broke up quite late in 1969 (about April 1), thus the April and May results may reflect high nutrient availability prior to the development of the summer population of aquatic plants. During the summer months when light intensity and water temperatures might be expected to lead to high productivity, a lower response occurred for want of nutrients. That is, the flask assays measured only the residual ability of reservoir water to stimulate growth after growth had already occurred and nutrients had not yet been recycled in available form. Later in the season, as daylight decreased and water temperatures declined, more nutrients became available as a result of a lower level of plant growth in less favorable environmental conditions. These nutrients then stimulated a second growth of organisms until temperature became a limiting factor. It is important to note that growth stimulating potential rather than biomass is measured by $\hat{\mu}_b$, hence it is theoretically possible for a water to exhibit no ability to stimulate algal growth when a very large production has already occurred. Such a situation, however, presumes nutrients available in amounts and proportions which in themselves are not growth limiting. In the case of Indian Creek Reservoir, Figures 31 to 34 have already shown low phosphorus and toxicity to be factors inhibiting growth response. Nevertheless, a comparison of data in Figures 35 and 36 with values of VSS for unfiltered B samples shown in Table XVIII, Appendix B, shows that in general the growth rate, $\hat{\mu}_b$, was high when the volatile suspended solids present

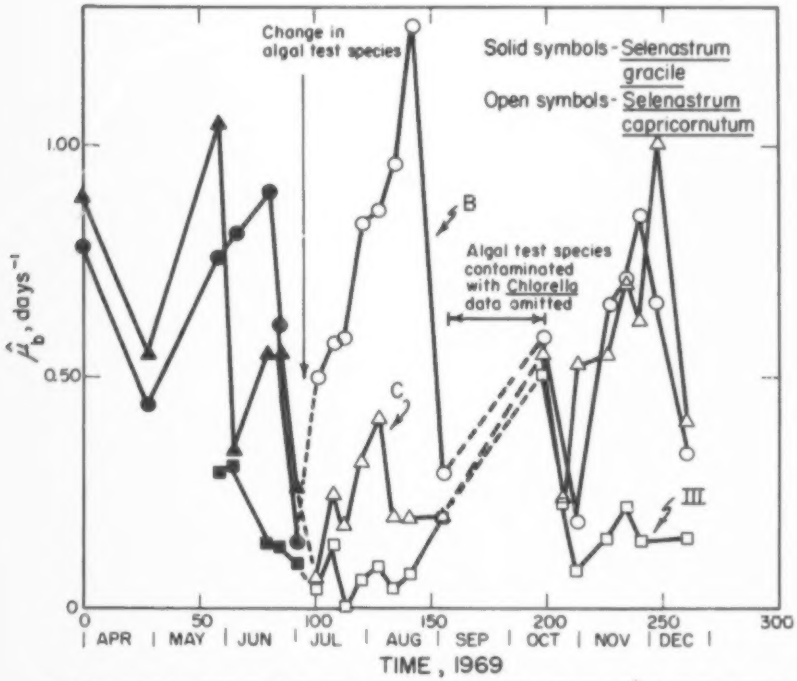

FIGURE 35. MAXIMUM SPECIFIC GROWTH RATE ($\hat{\mu}_b$) FOR UNDILUTED SAMPLES FROM THE INDIAN CREEK RESERVOIR SYSTEM

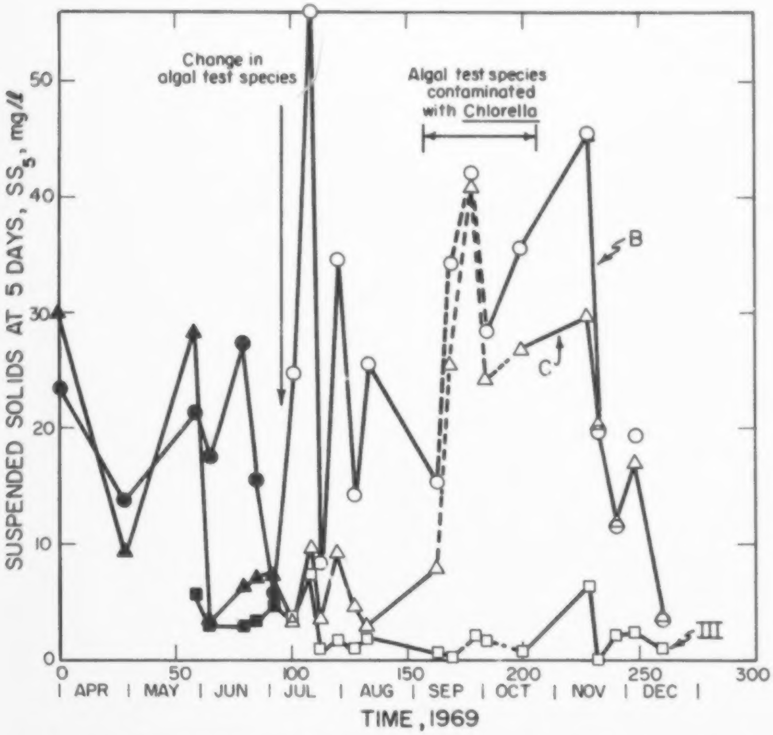

FIGURE 36. CELL PRODUCTION AFTER 5 DAYS OF GROWTH (SS_5) FOR UNDILUTED SAMPLES FROM THE INDIAN CREEK RESERVOIR SYSTEM

in the water was low, and vice versa. Presumably such a tendency would be more evident in a situation where nutrients are better balanced.

The results of cell production as measured by SS_5 (Figure 36) show substantially the same pattern as that observed for $\hat{\mu}_b$. This is to be expected because the parameter again measures only the ability of water to support new growth on the nutrient concentration present in an available form. A somewhat curious situation is evident for Sample B in July and August. Here the cell mass produced appears to be in inverse ratio with the rate of growth. Such a situation might be explained if it persisted throughout the year, but since such is not the case no obvious reason for this departure from the normal pattern is immediately apparent.

Low values of $\hat{\mu}_b$ and SS_5 observed for influent reclaimed water (L-III, Figures 35 and 36) were, as previously suggested, apparently due to some toxic factor or factors which depressed the growth of the test alga.

From Figures 35 and 36 it may be concluded that although the growth response of the test alga in Indian Creek Reservoir waters was inhibited by an imbalance of nutrients and, in some cases, toxicity, there was a seasonal variation in productivity of the water which is consistent with limnological and ecological conditions normal to impounded water.

CHAPTER V

EVALUATION OF RESULTS

Evaluation of specific findings of environmental, chemical, and biological observations of Indian Creek Reservoir is included in Chapter IV as a part of the discussion of individual subjects therein presented. Conclusions are drawn as deemed appropriate by the authors. These are summarized in Chapter VI. Therefore it seems appropriate to confine this chapter to an evaluation of what the Indian Creek Reservoir study has thus far shown concerning the reclamation and use of water from domestic wastes, and its import in the context of eutrophication of surface waters.

To begin with it must be borne in mind that although Indian Creek Reservoir is in 1970 providing recreational opportunity in the form of sport fishing and is soon to be developed for water contact sports as well, it was adapted rather than designed for such purpose. This is to say that the processes to be applied to secondary waste water effluent at the South Tahoe Public Utility District Plant were not originally selected with the objective of producing a water quality ideally suited to the multiple beneficial uses which are compatible in a wilderness. Instead they were the outgrowth of concern on the part of water quality control officials for the consequences of fertilizing surface waters with nutrients added by domestic use of water — nutrients which are only stabilized and not removed by the best, or even perfect, sewage treatment plants of the conventional type. Overriding even this national problem, and the national objective of its solution, was the unique situation existing in the Lake Tahoe Basin. Here it was deemed unacceptable, and on good evidence, to discharge into Lake Tahoe even water which meets U. S. drinking water quality standards, because in the matter of nutrients such standards exceed by some two orders of magnitude the concentrations presently found in the lake.

The factors underlying process design were therefore based on a number of rational concepts, not all of which were necessarily explicit in the decisions which followed:

1. The time is at hand when in many circumstances conventional waste water treatment processes must be extended to include nutrient removal or reduction.

2. Phosphorus is capable of triggering objectional algal growths, especially when low oxygen concentrations encourage algal species capable of utilizing nitrogen from the atmosphere.

3. We know how to remove phosphorus, therefore in the course of "pollution control" it should be removed as an act of faith if not of scientific necessity.

4. Nitrogen removal, although not immediately technologically developed, must in the future likewise be applied to waste water effluents.

5. At the present state of technology and knowledge of the sensitivity of Lake Tahoe, even the most highly treated waste water cannot be allowed to enter the lake, either directly or indirectly. Therefore, export from the basin is a practical necessity.

6. Given present aesthetic attitudes of people, exported effluents must be good enough to be acceptable to the exporter himself under normal conditions, i.e., were it not for the unique quality of Lake Tahoe.

7. Emerging standards of surface water quality must be met by any process of water reclamation.

8. A pioneering task of process development had to be undertaken if other concepts of water quality are to be achieved.

Given objectives, constraints, and problems such as the foregoing, and the political climate in which they must be resolved, the objectives of process design were necessarily different than might have been the case had the creation of a recreational reservoir been the water quality objective. This fact is extremely important in understanding what has been observed at Indian Creek Reservoir; and in considering what observations are required for the future.

The data herein presented and discussed show quite conclusively that the reclaimed water delivered to Indian Creek Reservoir during the first two years of operation was in itself phosphate limited as an algal growth medium. That is, it contained excess nitrogen in terms of the ability of organisms to utilize nitrogen and phosphorus. Moreover, in its undiluted state it was toxic both to trout and to the test alga (Selenastrum) used in bioassays of its growth potential. It is tentatively concluded herein that ammonia was the toxic factor. However, as the reservoir matured trout flourished in its waters.

Maturing of the reservoir involved a number of factors which the data identify, if they do not always explain. First the impounded reclaimed water was diluted by surface runoff and rainfall on the lake to a concentration of 80% reclaimed water and 20% runoff. Next, the influent ammonia content was reduced in the water mass from > 15 mg/ℓ to about 4 mg/ℓ. Although this latter value exceeds that often proposed as the maximum for trout, the survival and growth of trout after August 1969 indicates that the ammonia concentration was fully acceptable.

The mechanism of ammonia decrease in the reservoir cannot be isolated by a materials balance for nitrogen. A considerable amount was oxidized to the nitrate form. Some nitrogen was tied up in fish and in benthic and planktonic organisms. Some presumably moved downward with percolating water. Some emerged from the lake as midges and may have been blown away from the reservoir site. However, evidence discussed in Chapter IV leads to the conclusion that a very considerable amount of the influent nitrogen left the reservoir as nitrogen gas as a result of denitrification in the benthos.

During the summer of 1969 there was a period of low oxygen tension at the bottom of the reservoir. As late as October the benthic organisms were still predominantly dipterous larvae of low-oxygen tolerant species, although by that time the overlying water had been well mixed as far as oxygen was concerned. In numbers, the benthic population of dipterous larvae was profuse, but of limited species (i.e., of low species diversity), readily accounting for the well fed condition of trout collected for survey purpose. Evidence is presented which indicates that benthic life made use of phosphorus in the soil on which the reservoir was developed. Clearly the soil phosphorus, and any that may have washed in as sediments, had no identifiable effect on the concentration of phosphorus in the water mass. It continued to be phosphorus poor (N/P ratio of 29/1 to more than 70/1) throughout the period of observation reported (April 1969 - March 1970).

Because of the high N/P ratio, bioassays of the Indian Creek waters showed little beyond the fact of phosphorus starvation. They did, however, confirm the inability of test algal to grow in undiluted tertiary effluent, as well as the ability of a large degree of dilution (100 to 1) to overcome the toxic factor. They also exhibited the seasonal pattern which might be expected in an impoundment under the climatic and environmental conditions prevailing at Indian Creek Reservoir.

A plankton survey of the reservoir in April 1970 revealed a species distribution typical of impounded water. The overall observation of plankton throughout the year indicated a highly productive body of water. Vast quantities of winter eggs of Cladocera found in the benthos in October gave evidence of a previous large number of such organisms and, by inference, the algae on which they fed.

Good productivity of the reservoir was also evidenced by the oxygen profile in July which ranged from near saturation at the surface to zero at the bottom. At the same time, the concentration of chemical constituents of the water revealed that the reservoir was well mixed and not stratified, hence the oxygen profile reflected oxygen utilization in the bottom strata.

From a limnological and ecological viewpoint it is extremely important to observe Indian Creek Reservoir critically and carefully during the 1970-1971 season. The mixing of oxygen from top to bottom after August 1969 may be either a seasonal phenomenon or a sign that the reservoir was immature in July. If a strong oxygen profile does not develop in 1970, it may be expected that a greater diversity of species, and of dipterous larvae, will appear in the benthos. Consequently, benthic surveys should be programmed. Likewise it is important to learn from benthic and other analyses whether phosphorus in the soil was the source of this nutrient for the dipterous larvae on which the trout presumably fed. If such is the case, large releases of reservoir water during the summer should tend to dilute out the nutrients in the biota of the reservoir and, lacking new phosphorus from the soil, the reservoir would then become increasingly phosphorus poor. Conceivably this would be reflected in an even less diversity of biota and a lowered productivity of the reservoir. On the other hand, if nutrients in the soil at the time the reservoir was created were of little consequence, the principal event affecting the biosystem may be the magnitude of water releases.

The problem of bioassay as a measure of assessing the growth potential of Indian Creek Reservoir could well change in 1970 or later when the nitrogen stripping processes at STPUD are applied to a greater percentage of the exported water or achieve a greater reduction in nitrogen. Should the time come when water exported to Indian Creek Reservoir is at a N/P ratio of say 10/1, instead of more than 100/1 as during the period of study, the entire regime of the reservoir should change. Toxicity would presumably be minimized or eliminated and algal growth would continue to be limited by phosphorus; but the ecosystem which now evidently denitrifies the influent water could no longer exist except at the expense of making the water nitrogen limited rather than phosphorus limited, and so further reducing the productivity.

Although the foregoing possibilities remain speculative they are among the more compelling reasons why careful monitoring and evaluating of Indian Creek Reservoir should continue. From such data could evolve criteria for designing the processes necessary to make reclaimed water as productive and as sterile as desired for the use to which it is to be put. Thus it might be possible to avoid economic loss in processes which may not in reality serve the purpose for which they are intended.

In any event Indian Creek Reservoir affords an unprecedented opportunity to observe for practical as well as scientific reasons what may be expected from an impoundment of water reclaimed for domestic return flows. With specific reference to Lake Tahoe, it permits the exploration and development of the knowledge and processes needed to make possible future reuse of reclaimed water in the Basin, without injuring the quality of the lake during the period of development.

CHAPTER VI

SUMMARY AND CONCLUSIONS

During the period March 1969 through April 1970 environmental, chemical, and biological observations and analyses were made of waters at Indian Creek Reservoir under Demonstration Grant No. 16010 DNY to the Lake Tahoe Area Council by the Federal Water Quality Administration.

Indian Creek Reservoir is the terminus of a 27-mile pipeline by which the South Tahoe Public Utility District exports reclaimed water from the Lake Tahoe Basin. During the dry season water is released from the reservoir for irrigation of crops. At other times of the year the reservoir is filling with exported water, plus a lesser amount of seasonal runoff from the local drainage basin.

The general purpose of the demonstration grant study was to determine whether advanced waste treatment processes at the upper limit of current technology are adequate to reduce nutrients below the level at which they may seriously accelerate the rate of eutrophication of surface waters. Although the treatment processes were dependent upon available technology, the specific objective of the study was to assess their adequacy by:

1. Determining the effects of reclaimed water on the physical, chemical, and biological parameters of Indian Creek Reservoir by which eutrophication potential and water quality may be judged.

2. Relating the characteristics of the reservoir to the nutrient and biostimulatory characteristics of its influent reclaimed water.

3. Evaluating the effects of nutrients present in the underlying soil on which the reservoir was developed.

4. Correlating the results obtained at Indian Creek Reservoir with laboratory and pilot pond studies of the same reclaimed water diluted with Lake Tahoe water.

Pursuant to such objectives a climatological and hydrological study was made of the reservoir. Water samples were taken at approximately weekly intervals for chemical analysis of influent reclaimed water, impounded water, and water discharged at a constant low rate from the reservoir. Impounded water was sampled within the top 0.5 meters of depth at three stations. At monthly intervals samplings were made from top to bottom. Discharged water came from mid-depth of the reservoir at a single point of origin of a pipeline. Influent reclaimed water samples were drawn from the pressure export pipeline. All samples were analyzed chemically for a number of constituents, including various forms of nitrogen and phosphorus. Flask bioassays of algal growth response were made weekly. General observations were made of biological life on and in the reservoir. A benthic invertebrate survey was made in October 1969. Data on benthic and planktonic microscopic organisms were observed periodically; and a full plankton survey made in April 1970.

Based on the results obtained during the report period (March 1969 to April 1970), the following conclusions and observations are made.

1. The water impounded in Indian Creek Reservoir during 1969 was approximately 20 percent surface runoff and 80 percent reclaimed water. Consequently its quality was more influenced by reclaimed water than by surface runoff.

2. Because the drainage area above the reservoir is small (1700 acres) it may be expected that as the volume of exported water increases, the quality of impounded water will increasingly be influenced by reclaimed water.

3. Estimates of runoff and evaporation rates previously reported to the STPUD by its engineering consultants appear to be sufficiently valid to permit a reasonable water budget estimate for Indian Creek Reservoir.

4. Year round observations designed to establish more accurate runoff and evaporation rates should be made in order to refine the limnological knowledge of the reservoir as it matures.

5. Infiltration rates as of mid-1969 were of the order of 0.035 ± ft of water per day; a value which is both reasonable and plausible.

6. The clarity of Indian Creek Reservoir water during the period of observation was typical of shallow impoundments of relatively good quality water. During the period June 1969 through March 1970 it varied from 0.84 to 3.46 meters (Secchi disk). In April 1970 it was as great as 6 meters.

7. Water temperatures in the upper stratum of the reservoir, where light and other environmental factors are most favorable to plankton growth, reach an 18°-22°C range also favorable to biological activity. In winter they fall below the lower limit for biological activity.

8. With only minor exceptions, the observed data on physical characteristics of the reservoir are in line with typical and explainable phenomena, although not in sufficient detail to permit statistical evaluations.

9. The importance of wind movement in describing and evaluating the limnology at Indian Creek Reservoir is such that a more detailed and continuous observation of wind direction and velocity should be a part of any continued surveillance of the reservoir.

10. Chemical analyses of impounded and discharged water show that there was little difference in conservative chemical quality from top to bottom. Dissolved oxygen declined with depth in July as did alkalinity (carbon source) and ammonia (nutrient source).

11. COD in reservoir water was not demonstrably related to VSS or any other of the parameters evaluated.

12. There is good evidence that iron in Indian Creek Reservoir played an important role in the life cycle of biota which appeared in the surface stratum of the impounded water.

13. pH is a sensitive parameter of the limnological characteristics of Indian Creek Reservoir, however, it varied in impounded water only from 7.7 to 8.5 as compared to 7.4 to 8.8 in the influent reclaimed water.

14. In terms of conductivity and chemical components the water impounded at Indian Creek Reservoir is of good quality for irrigation water.

15. Differences in concentration of conservative quality factors such as chloride and calcium in influent and impounded water in Indian Creek Reservoir were clearly the result of dilution.

16. Substantial evidence was found that bicarbonate alkalinity was used as a source of carbon by the biota of Indian Creek Reservoir during the period of study.

17. Prior to September 1969 the impounded water was poorly mixed and the oxygen profile reached zero at the bottom level. However, the reservoir was not thermally stratified.

18. The reservoir became well mixed in September 1969. Thereafter results of horizontal and vertical distribution of oxygen indicated that a single observation at one sampling station was a sufficient basis for computing the oxygen resource of the impounded water mass.

19. The impounded water was quite homogeneous during the period of study. Consequently only the dissolved oxygen concentration in the water mass was particularly changed by mixing of the reservoir.

20. It is not yet known whether poor mixing was a seasonal phenomenon or an aspect of a new limnologically immature impoundment. Continued observation of the reservoir during another season should answer this question and so make possible predictions of water quality in the reservoir.

21. Phosphorus was considered the limiting nutrient in reservoir waters. N/P ratios of influent reclaimed water were of the order of 150/1. In the impounded water the ratio remained above 29/1 during the period of study.

22. With but little aid from dilution the NH_3-N concentration changed from > 15 mg/ℓ in the influent water to some 4 mg/ℓ in the impounded water. Evidence is submitted to show that the reduction was almost certainly due to nitrification—denitrification rather than growth of biomass.

23. Influent reclaimed water exported to Indian Creek Reservoir proved toxic to trout in field tests, and to algae in laboratory assays. Nevertheless, trout planted in the reservoir after October 1968 showed no effects. Ammonia concentration in the reclaimed water was the presumed toxic material.

24. A benthic invertebrate survey by the FWQA in October 1969 showed an average of 464 dipterous larvae per square foot in the 17 areas sampled. These were all essentially of three species of low-oxygen tolerant types, although a previous condition of low oxygen in the bottom stratum of water was overcome as early as September 1969.

25. Although the benthic invertebrate survey showed a high yield of biota, the diversity of biota was unusually limited. The same was observed in Indian Creek itself just below the discharge of Indian Creek Reservoir.

26. There is evidence that although the water mass was severely phosphorus limited, benthic organisms made use of phosphorus in the soil underlying the reservoir.

27. In the impounded water rainbow trout flourished at an NH_3-N level of about 4 mg/ℓ, although 2 mg/ℓ is often considered a maximum for such species. Trout planted in Indian Creek Reservoir in August 1969 increased in length from 1.7 to 6 in., and from 4.5 to 8.9 in., in length by October 1969.

28. Bioassays of impounded water showed limited growth, probably because of unfavorable N/P ratios, although a seasonal pattern of a readily explainable nature was evident.

29. Essentially no growth occurred in bioassays of undiluted reclaimed water, indicating the presence of some toxic material. When diluted to one percent concentration with Lake Tahoe water the toxic effect was overcome to the extent that algal growth proceeded.

30. From plankton samples taken over a period of time it is evident that a varied plankton population indicative of good productivity had developed in Indian Creek Reservoir by July 1969.

31. A plankton survey of impounded waters and bottom muds made in April 1970 showed a species distribution characteristic of impounded water. However, the reservoir appeared to be a highly productive body of water.

32. The plankton survey showed Indian Creek near the reservoir dam to have a biota characteristic of an enriched water.

33. Monitoring of Indian Creek Reservoir, including benthic surveys, should be continued to reveal any changes which may result from:

    a. greater removals of nitrogen at the STPUD water reclamation plant

    b. greater releases of impounded water during the summer season

    c. reduction in soil phosphorus as a source of phosphorus.

34. Observation of Indian Creek over a period of time may make it possible to design water reclamation processes capable of producing a water of balanced quality suited to a broad spectrum of recreational uses yet not subject to algal blooms.

35. A major finding of the study is that by simple impoundment of the water exported from the Tahoe Basin, its quality was changed from that untenable to fish and certain algae, to one of good productivity of both, within the limits of available nutrients.

36. In evaluating the results of the study it should be borne in mind that the nitrogen content of the exported water did not represent the ultimate degree of removal to be expected in water reclamation by the STPUD, and that Indian Creek Reservoir may be expected to undergo further changes in the process of maturing.

37. Waste water reclamation at South Tahoe has progressed to the point where under normal circumstances water would not be exported. However, because Lake Tahoe is more unique than normal Indian Creek Reservoir provides a good proving ground outside the Tahoe Basin in which to evaluate the processes and develop the scientific knowledge needed to permit its future use within the Basin if desired.

APPENDIX A

TABLE XVII

MAXIMUM, MINIMUM, AND AVERAGE VALUES OF QUALITY FACTORS IN RECLAIMED WATER (COMPUTED FROM MONTHLY REPORTS OF THE SOUTH TAHOE PUBLIC UTILITY DISTRICT) (All Values in mg/l Except Turbidity, pH, and Coliforms)

Date	B.O.D.	COD	Suspended Solids	MBAS	Turbidity (JTU)	pH	[illegible]	Coliform* MPN	Nitrogen				Phosphate	Alkalinity	Hardness	Total Dissolved Solids	Chloride	Sulfate
									Organic	Ammonia	Nitrate	Nitrite						
[illegible] Apr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	- - [illegible]	[illegible]	[illegible]	- - -
May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jul	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aug	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sep	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oct	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nov	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dec	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]
[illegible] Jan	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]
Feb	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	[illegible]	[illegible]
Mar	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	32 23 26	48 14 28
Apr	[illegible]	[illegible]	- - -	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	- - -	- - -	[illegible]	[illegible]	[illegible]	[illegible]	170 70 145	- - -	35 15 22	26 15 19

[illegible]

TABLE XVII (Continued)

Date	BOD	COD	Suspended Solids	MBAS	Turbidity	pH	Chlorine Residual Instantaneous	Coliform (mpn)	Nitrogen				Phosphate	Alkalinity	Hardness	Total Dissolved Solids	Chloride	Sulfate
									Organic	Ammonia	Nitrate	Nitrite						
1969 Cont. May	1.0 0.1 0.5	15.4 4.7 9.7	- - -	0.27[a] 0.10 0.19	1.2 0.2 0.5	8.1 6.8 7.4	4.0 0.5 1.4	2.2 2.2 2.2	- - -	- - -	1.75 0.00 0.39	0.58 0.01 0.10	0.70 0.07 0.29	272 137 213	170 80 135	- - -	33 18 22	38 15 22
Jun	4.1 0.2 1.2	10.6 3.2 7.2	- - -	0.14 0.00 0.09	1.0 0.1 0.3	8.8 6.7 7.6	2.7 0.4 0.9	16.0 2.2 3.0	- - -	15.3 11.5 14.0	4.40 0.00 0.90	1.25 0.00 0.19	0.37 0.02 0.20	252 149 206	156 74 120	- - -	25 11 17	28 15 19
Jul	1.8[a] 0.4 0.8	18.9 3.5 11.1	- - -	0.25[a] 0.07 0.16	1.0 0.1 0.4	9.4 6.6 7.5	3.0 0.4 1.3	5.1 2.2 2.5	- - -	13.4[a] 11.1 12.1	6.70 0.38 2.45	5.50 0.09 2.40	1.14 0.00 0.26	243 102 173	166 58 110	- - -	30 17 22	48 17 27
Aug	4.9[a] 0.2 1.5	16.2 3.2 8.5	- - -	0.27[a] 0.01 0.13	0.8 0.1 0.3	8.1 6.5 7.1	3.3 0.6 1.5	5.1 2.2 2.3	- - -	- [a] - 15.7	7.8 0.0 2.2	2.80 0.00 0.26	0.20 0.00 0.12	247 178 214	154 120 141	- - -	28 17 24	56 15 29
Sep	3.8 0.2 1.2	14.2 0.9 8.1	- - -	0.14[a] 0.00 0.07	0.4 0.1 0.2	7.4 6.8 7.0	2.8 0.2 1.9	2.2 2.2 2.2	- - -	17.9[a] 10.7 14.2	3.3 0.0 1.1	1.98 0.02 0.32	0.24 0.00 0.08	250 120 200	174 118 144	- [a] - 320	60 17 26	56 18 29
Oct	1.4[a] 0.1 0.9	12.8 0.6 5.2	0 0 0	0.20[a] 0.01 0.12	0.8 0.1 0.2	8.1 6.7 7.1	3.7 1.2 2.4	8.8 2.0 2.2	- - -	19.8 10.9 15.9	2.4 0.1 1.1	1.58 0.01 0.26	0.29 0.01 0.13	430 214 270	176 108 149	450 170 326	28[a] 20 23	29 12 21
Nov	3.9[a] 0.4 1.8	21.7 1.7 8.7	0 0 0	0.35[a] 0.08 0.22	1.3 0.3 0.5	8.7 6.6 7.4	6.0 0.9 3.0	2.2 2.0 2.0	- - -	22.4 6.0 17.1	3.9 0.0 1.1	0.36 0.01 0.12	0.27 0.00 0.08	290 175 230	170 134 154	520 152 355	31[a] 22 26	56[a] 33 44
Dec	6.7[a] 0.2 1.7	24.0 2.9 9.8	0 0 0	0.18[a] 0.00 0.07	1.5 0.3 0.6	8.3 6.6 7.4	4.7 0.7 2.7	5.0 2.0 2.1	- - -	27.1 13.0 19.4	1.2 0.0 0.3	0.23 0.00 0.06	0.68 0.02 0.17	293 156 215	178 114 156	390 220 324	28[a] 21 25	52[a] 30 37
1970 Jan	2.4[a] 0.2 0.7	18.1 1.1 7.5	- - -	0.09[a] 0.07 0.08	1.8 0.3 0.7	8.4 6.8 7.0	6.0 0.4 3.1	2.2 2.0 2.0	- - -	25.6 8.6 16.4	1.1 0.0 0.6	0.58 0.00 0.13	0.75 0.06 0.28	233 153 194	166 106 149	320[a] 280 303	33[a] 15 23	36[a] 19 27
Feb	5.0[a] 0.5 2.3	20.7 2.4 8.9	0 0 0	0.14[a] 0.10 0.12	0.6 0.2 0.4	8.2 7.1 7.7	3.6 0.7 2.2	2.0 2.0 2.0	- - -	25.4 17.2 19.8	1.3 0.0 0.4	0.05 0.00 0.03	0.43 0.09 0.20	247 135 211	178 108 156	300[a] 300 300	25[a] 18 22	31[a] 16 20

[a] Fewer than ten numbers indicated.

APPENDIX B

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TABLE XVIII

INDIAN CREEK RESERVOIR ANALYSES

Date	Sample Type	Smp. Depth	Time	Secchi Disk	Temperature		Unfiltered Sample									.045 µ Millipore Filtered Samples												
					Water	Air	Susp. Solids	Vol. Susp. Solids	Nitrogen as N		Total Phos.	COD	BOD_5	DO	Inorg. C	Nitrogen as N					Phosphorus as P		Ca	Cl^-	Fe	pH	Alk. as $CaCO_3$	Cond. (10^{-6})
									Org.	NH_3						Org.	NH_3	NO_3	NO_2	Total	PO_4	Total						
		ft	[illegible]	ft	°C	°C	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l	mho
[illegible]	[illegible]												[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]												[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]												[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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TABLE XVIII. Continued

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Temperature		Unfiltered Samples									0.45 μ Millipore Filtered Samples												
							[illegible]	[illegible]	Nitrogen as N		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Nitrogen as N					Phosphorus as P		[illegible]	[illegible]	[illegible]	pH	Alk. as CaCO3	Cond.
					Water	Air			[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	Total	[illegible]	Total						
							mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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NOTE: Unless otherwise noted blanks or dashes indicate no analysis made.

[a] Water sample collected by the riprap at the north dam at Indian Creek Reservoir (ICR).

[b] Effluent sample collected at the discharge weir at ICR.

[c] Sediment from a normally dry creek bed on the east side of ICR.

[d] Creek at the southeast side of ICR.

[e] Indian Creek located at the south end of ICR.

[f] Bay at ICR.

[g] Tertiary effluent from South Tahoe Public Utility District's (STPUD) Waste Water Treatment Plant.

[h] Number location of permanent buoy where composite samples over 24-hr were collected.

[i] Depth that composite samples over 24-hr at (buoy) Station No. 1, 2, and 3 were collected.

[j] STPUD tertiary effluent collected at the Luther Pass pumping station.

[k] Data recorded in Table XIX.

TABLE XIX

MEASUREMENTS OF VERTICAL AND HORIZONTAL DISTRIBUTION OF WATER QUALITY FACTORS THROUGHOUT 24 HOURS

Sampling Date	Station	Time of Sampling	Sample Depth meters	Temperature °C	pH	Alk. mg/l as CaCO₃	Dissolved Oxygen mg/l	Inorganic[a] Carbon mg/l
[illegible] 7/16	1[1]	1150	0.0	21.5	8.4	116	6.8	26.4
			2.0	19.8	7.9	129	2.6	32.3
			5.0	18.5	7.9	118	1.5	29.5
			11.0	18.0	7.8	117	0.6	29.2
			14.0	18.0	7.8	120	0.0	30.0
	2	1230	0.0	21.5	8.4	110	6.4	26.4
			4.5	19.5	8.1	115	4.2	27.1
			7.5	18.4	7.9	118	2.0	29.5
			10.5	18.0	7.8	117	0.9	29.2
	3	1340	0.0	22.0	8.4	108	6.7	25.9
			4.0	20.1	8.3	110	5.0	26.4
			7.0	18.5	8.0	114	2.5	27.4
			10.0	18.5	7.7	118	1.6	29.5
	Between Sta. 3 and Indian Creek	1500	0.0	21.8	8.4	105	7.0	26.2
			3.0	20.[illegible]	8.3	107	5.8	26.[illegible]
			5.0	19.0	8.0	114	1.8	27.4
	1	1550	0.0	21.8	8.5	111	7.0	26.0
			2.5	21.0	8.3	115	5.8	27.1
			5.0	20.0	8.0	116	4.0	27.8
			9.0	18.5	7.9	117	1.0	29.2
			14.0	17.8	7.8	121	0.5	30.2
	2	1615	0.0	22.3	8.5	110	7.7	26.9
			2.5	20.8	8.3	113	5.9	27.1
			5.0	19.0	8.0	127	2.8	30.[illegible]
			10.5	18.0	7.9	11[illegible]	1.5	29.0
	3	1630	0.0	22.2	8.4	110	7.6	26.4
			2.5	20.5	8.4	111	6.9	25.6
			5.0	18.7	8.0	120	2.0	28.8
			8.0	18.5	8.0	115	1.5	27.6
	1	2100	0.0	21.4	8.3	110	7.0	26.4
			2.5	20.6	8.2	112	6.5	26.9
			6.0	18.0	7.8	123	2.1	30.8
			9.5	17.6	7.7	118	1.0	29.5
			14.0	17.5	7.7	121	0.5	30.2
	2	2145	0.5	21.5	8.3	112	6.7	26.9
			2.5	20.5	8.2	111	6.1	26.0
			6.5	18.4	7.9	129	2.[illegible]	31.8
			10.5	17.5	7.7	111	0.4	29.2
	3	2210	0.0	22.0	8.3	110	5.5	26.4
			2.5	19.8	8.1	112	5.4	26.9
			5.5	18.5	7.9	117	2.6	29.1
			8.5	17.8	7.8	112	1.7	29.1
7/17	1	0030	0.0	20.4	7.9	105	6.4	25.8
			2.5	20.0	7.9	108	6.5	26.1
			5.5	18.0	7.6	118	2.0	29.1
			9.0	17.4	7.5	115	1.1	29.9
			14.0	17.0	7.4	110	0.2	30.2
	2	0100	0.0	20.8	7.9	108	6.6	26.8
			2.5	20.0	7.9	117	5.7	29.2
			5.5	18.0	7.6	107	2.4	26.8
			8.0	17.8	7.8	114	0.9	27.4
	3	0420	0.0	20.4	8.0	108	6.7	25.7
			2.5	20.2	7.9	105	6.6	27.0
			5.5	18.4	7.7	115	2.9	28.8
			8.0	17.8	7.5	118	1.4	30.8

TABLE XIX (Continued)

Sampling Date	Station	Time of Sampling	Sample Depth meters	Temperature °C	pH	Alk. mg/ℓ as $CaCO_3$	Dissolved Oxygen mg/ℓ	Inorganic Carbon mg/ℓ
7/17 (Cont.)	1	1140	0.5	22.2	8.3	110	6.6	26.4
			3.5	20.9	8.2	112	5.9	26.9
			6.5	18.8	7.9	123	2.3	30.8
			9.5	18.1	7.8	119	1.4	29.8
			14.0	18.0	7.7	120	0.6	30.0
	2	1155	0.5	22.2	8.3	112	6.5	26.9
			3.5	20.5	8.2	111	5.8	26.6
			6.5	18.8	7.9	124	2.4	31.0
			10.5	18.2	7.8	118	0.6	29.5
	3	1205	0.5	22.2	8.3	110	6.8	26.4
			3.5	20.5	8.2	110	6.1	26.4
			6.5	18.7	8.0	115	2.0	27.6
			8.5	18.4	7.8	118	1.1	29.5
9/15	1	1245	0.5	19.0	7.8	122	4.6	30.5
			3.5	18.5	7.8	123	4.6	30.8
			6.5	18.2	7.8	123	4.4	30.8
			9.5	18.2	7.8	124	4.3	31.0
			12.0	18.0	7.8	124	3.8	31.0
	2	1320	0.5	18.7	7.9	125	4.8	31.2
			3.5	18.5	7.8	125	4.8	31.2
			6.5	18.2	7.8	124	4.6	31.0
			9.5	18.0	7.8	123	4.2	30.8
			11.0	17.8	7.8	125	3.8	31.2
	3	1345	0.5	18.7	7.9	125	4.7	31.2
			3.5	18.5	7.9	123	4.6	30.8
			6.5	18.4	7.9	124	4.7	31.0
			8.5	17.8	8.4	131	4.2	31.4
	1	1645	0.5	19.0	7.9	122	5.8	30.5
			3.5	19.0	7.9	123	5.5	30.8
			6.5	18.8	7.8	126	5.3	31.5
			9.5	18.6	7.8	122	5.1	30.5
			12.0	17.8	7.8	124	4.2	31.0
	2	1715	0.5	18.8	7.9	124	4.0	31.0
			3.5	18.3	7.9	124	5.2	31.0
			6.5	18.2	7.9	126	4.8	31.5
			9.5	18.0	7.8	122	4.4	30.5
			11.0	18.0	7.8	125	3.8	31.2
	3	1735	0.5	18.2	7.9	126	4.9	31.5
			3.5	18.3	7.9	123	5.1	30.8
			6.5	18.2	7.8	126	4.7	31.5
			8.5	18.0	7.8	123	3.8	30.8
	1	2100	0.5	18.2	7.9	125	5.3	31.2
			3.5	18.3	7.8	125	4.5	31.2
			6.5	18.2	7.8	124	5.0	31.0
			9.5	17.8	7.8	124	3.3	31.0
			12.0	17.5	7.8	126	5.4	31.5
	2	2115	0.5	18.1	7.9	129	3.8	32.2
			3.5	18.1	7.9	127	4.6	31.8
			6.5	18.2	7.8	129	4.9	32.2
			9.5	17.9	7.8	125	4.0	31.2
			11.0	17.1	7.7	123	5.0	30.8
	3	2130	0.5	18.1	7.8	125	4.1	31.2
			3.5	18.1	7.8	123	5.0	30.8
			6.5	18.0	7.8	124	4.7	31.0
			8.5	17.8	7.8	126	4.1	31.5
	1	2355	0.5	17.5	7.9	126	5.3	31.5
			3.5	17.8	7.8	126	5.6	31.5
			6.5	17.9	7.8	125	4.6	31.2
			9.5	17.8	7.8	125	4.0	31.2
			12.0	17.5	7.7	126	2.9	31.5
9/16	2	0015	0.5	18.1	7.9	129	5.1	32.2
			3.5	18.0	7.9	128	5.1	32.0
			6.5	18.0	7.8	125	5.1	31.2
			9.5	17.3	7.8	126	4.1	31.5
			11.0	17.1	7.8	122	3.8	30.5
	3	0036	0.5	17.9	7.8	125	5.3	31.2
			3.5	18.2	7.9	125	5.3	31.2
			6.5	17.7	7.8	125	4.5	31.2
			8.5	17.3	7.8	126	5.0	31.5

TABLE XIX (Continued)

Sampling Date	Station	Time of Sampling	Sample Depth meters	Temperature °C	pH	Alk. mg/ℓ as $CaCO_3$	Dissolved Oxygen mg/ℓ	Inorganic Carbon mg/ℓ
9/16 (Cont.)	1	0630	0.5	17.2	7.8	125	5.0	30.8
			3.5	17.2	7.8	125	5.0	31.2
			6.5	17.1	7.9	124	4.2	31.0
			9.5	17.1	7.8	125	3.8	31.2
			12.0	17.1	7.8	127	3.3	31.8
	2	0645	0.5	17.2	7.9	125	4.7	31.2
			3.5	17.2	7.8	125	4.6	31.2
			6.5	17.2	7.9	128	4.6	32.0
			9.5	17.0	7.8	128	3.7	32.0
			11.0	16.9	7.8	128	3.8	32.0
	3	0700	0.5	17.2	7.9	132	5.0	33.0
			3.5	17.1	7.9	128	4.9	32.0
			6.5	17.1	7.9	126	5.4	31.5
			8.5	17.4	7.9	124	4.9	31.0
	1	1230	0.5	18.5	7.8	127	4.7	31.8
			3.5	18.3	7.9	124	4.6	31.0
			6.5	18.0	7.8	125	4.4	31.2
			9.5	17.8	7.8	125	4.4	31.2
			12.0	17.7	7.8	125	4.2	31.2
	2	1200	0.5	18.4	7.9	126	4.6	31.5
			3.5	18.2	7.8	126	4.8	31.5
			6.5	18.0	7.8	125	4.4	31.2
			9.5	18.0	7.8	124	4.6	31.0
			11.0	18.0	7.9	125	4.6	31.0
	3	1210	0.5	18.4	7.8	125	4.8	31.8
			3.5	18.2	7.8	126	4.4	31.5
			6.5	18.0	7.8	125	4.6	31.2
			8.5	17.6	7.8	125	4.5	31.2
11/19	1	1125	0.5	6.5	8.0	135	8.9	33.8
			3.5	6.3	8.0	136	8.6	34.5
			6.5	6.2	7.9	132	9.2	33.0
			9.5	6.2	8.0	121	9.0	32.8
			12.0	6.0	7.9	133	9.3	33.2
	2	1145	0.5	6.5	7.9	136	9.1	34.0
			3.5	6.2	7.9	135	9.2	33.8
			6.5	6.2	7.9	131	9.6	32.8
			9.5	6.0	7.9	130	9.2	32.5
	3	1200	0.5	6.4	8.0	136	9.3	34.0
			3.5	6.3	7.9	139	9.0	34.8
			6.5	6.2	7.9	127	9.3	31.8
			8.5	6.2	7.9	133	9.0	33.2
1970 2/3	2	1315	0.5	4.2	8.0	127	10.9	31.1
			3.5	3.5	8.0	126	11.2	31.0
			6.5	3.5	8.0	127	11.2	31.0
			9.5	3.5	8.0	127	11.1	31.1

[a] Calculated from alkalinity, pH, and temperature data [24].

[b] Permanent sampling stations (see Figure 6).

TABLE XX

MODIFIED SKULBERG NUTRIENT MEDIUM [18]

Macronutrients	Final Concentration (mg/ℓ)	Micronutrients (Adapted from Myers, 1951)*	Final Concentration (mg/ℓ)
$NaNO_3$	46.7	$Co(NO_3)_2 \cdot 6H_2O$	0.0012
$Ca(NO_3)_2 \cdot 4H_2O$	5.9	$(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$	0.0122
K_2HPO_4	3.1	$CuSO_4 \cdot 5H_2O$	0.0200
$MgSO_4 \cdot 7H_2O$	2.5	$Zn(C_2H_3O_2)$	0.0382
Na_2CO_3	2.1	$MnCl_2 \cdot 4H_2O$	0.050
Fe EDTA ($FeSO_4$ + Na_2 EDTA)	0.2 as Fe	H_3BO_3	0.50

*Myers, J. (1951). "Physiology of the Algae," Ann. Rev. Microbiology, 6:165-180.

APPENDIX C

TABLE XXI

ANALYSES OF SURFACE WATER - INDIAN CREEK RESERVOIR DISCHARGE (DWR DATA)

Water[a] Quality Factor	Sampling Date														
	1968		1969												
	6/20	7/17	7/9	7/16	7/23	8/6	8/20	8/27	9/5	9/11	9/17	9/24	10/1	10/8	10/22
Discharge (cfs)	-	-	0.01	0.01	0.01	0.01	0.01	15.4	0.01	0.01	14	0.01	0.01	0.01	0.01
Temp. °F	-	-	76	61	64	73	78	67	67	66	64	65	59	62	46
DO	-	-	-	-	-	-	7.1	-	12.5	-	8.0	-	-	-	-
pH	9.2	9.0	7.9	9.7	7.4	-	9.3	-	8.0	8.3	7.9	8.0	7.7	8.5	7.8
Conduct. micromhos at 25°C	520	572	554	559	545	590	404	585	400	590	581	586	590		599
Cl	5.5	58													
NO_3-N	0.80	1.7													
NO_2-N	5.5	5.0													
Org-N	2.6	2.2													
NH_3-N	2.8	3.1													
T + Org PO_4	1.4	2.0													
Turbidity	-	-	35	85	20			5.5			10	22	6.5	4.5	6.5

[a] Values in mg/l except discharge, temperature, pH, conductivity, and turbidity.

TABLE XXII

DISCHARGE DATA ON INDIAN CREEK RESERVOIR[a]

1969 Date	Staff Reading	Flow cfs	Release Time		Flow (AF per)		
			On	Off	Day	Period	Season
August							
13	0.85	12.7	0800		16.8		
14	0.85	12.7			25.2		
15	0.80	11.0			21.8		
16	0.80	11.0			21.8		
17	0.78	10.8		1100	9.8		
Total						95.4	
August							
26	0.90	14.1	1000		15.5		
27	0.88	13.4			26.6		
28	0.88	13.4			26.6		
29	0.88	13.4			26.6		
30	0.88	13.4			26.6		
31	0.88	13.4			26.6		
September							
1	0.88	13.4		1400	15.5		
Total						164.0	
September							
16	0.85	12.7	0900		15.8		
17	0.85	12.7			25.2		
18	0.85	12.7			25.2		
19	0.85	12.7			25.2		
20	0.85	12.7			25.2		
21	0.85	12.7			25.2		
22	0.85	12.7			25.2		
23	0.85	12.7		0900	9.4		
Total						176.4	436

[a] Discharge at all other times considered negligible.

TABLE XXIII

ANALYSES OF SURFACE WATER (DWR PRELIMINARY DATA)

Water[a] Quality Factor	Stevens Lake at Outlet			Indian Creek						
				Stevens Lake Valley		Highway 89	Diamond Valley Road		Dutch Valley	
	Date			Date		Date	Date		Date	
	6/20/68	6/27/69	9/5/69	6/20/68	9/11/69	9/11/69	9/11/69	9/5-10/22/69	9/11/69	9/5-10/22/69
Temp. °F	-		68		75	68	68	47 - 68	68	45 - 70
DO	-		11.0		9.9	7.7	7.9	7.1-7.9	8.8	8.2-10.2
pH	9.4		9.1	9.4	7.5	110	7.1	7.1-7.3	7.7	7.3- 7.7
Conduct. micromhos at 25°C	90	83		90	117		195	72 -292	120	81 - 236
Cl	0.0			0.0						
NO_3-N	0.0			0.00						
NO_2-N	0.02			0.02						
Org-N	1.0			1.0						
NH_3-N	0.06			0.06						
T + Org PO_4	0.16	1.5	1.8	0.16						
Turbidity					2.7	4.6	19			3.1- 13

[a] Values in mg/ℓ except temperature, pH, conductivity, and turbidity.

TABLE XXIV

ANALYSES OF GROUND WATER (DWR AND USGS DATA)

Water[a] Quality Factor	Domestic Well 11N/19E-35K1			Domestic Well 11N/19E-36H1			Domestic Well 11N/20E-29H2		
	Date			Date			Date		
	8/15/56	8/65	8/6/68	8/14/56	9/17/69	10/1/69	8/15/56	9/17/69	10/22/69
Temp. °F	54	-	54	52	60	57	58	60	55
Conduct. micromhos at 25°C	80.1	96 (6/66)	78	145	155	155	303	310	310
pH	7.1	6.6 (6/66)	7.3	7.0	6.3	6.3	7.3	7.5	7.3
Ca	7.8	9.7	-	14			33		
Mg	2.6	1.7	-	5.4			12		
Na	5.3	5.4	5.7	8.3			15		
K	1.3	1.0	-	1.4			4.4		
(CO_3)	0	0	0	0			0		
(HCO_3)	51	55	44	73			178		
SO_4	1.9	0.8	-	3.8			16		
Cl	0.5	1.4	0.8	4.0			1.0		
NO_3	0.0	0.5	-	0.0			0.0		
F	0.0	-	-	9.4			0.0		
B	0.05	0.0	-	0.02			0.11		
SiO_2	35	-	-	38			58		
TDS	80	66	-	120			228		
% Na	27	27	-	23			19		
Hardness $(CaCO_3)$	30	31	-	57			130		

[a] Values in mg/ℓ except temperature, pH, conductivity, and % Na.

TABLE XXV

ANALYSES OF SURFACE WATER, WEST FORK CARSON RIVER

Location: West Fork Carson River at Woodfords

Station: 7G82300.00

Water Year	Prior High-Low Record		63 64	64 65	65 66	66 67	67 68	68 69
EC	High	89.3	84	80	87	79	85	80
μ mhos	Low	36.9	59	47	46	44	50	36
Temp	High	66	59	54	64	51	53	58
	Low	32	32	35	33	33	31[a]	32
DO	High	11.7	12.3	11.6	11.9	11.7	10.6	12.6[a]
mg/ℓ	Low	7.6	8.2	8.8	8.2	9.2	8.8	9.6
% Sat.	High	103	103	104	110[a]	103		
	Low	66	96	100	98	99		
Field	High	8.0	8.0	7.5	7.5	7.3	7.7	7.9
pH	Low	6.9	7.1	7.2	7.3	7.1	7.4	7.1
Ca	High	11	11	9.6	8.6		9.1	8.6
mg/ℓ	Low	4.0	7.6	5.6	6.0		5.7	4.2
Mg	High	3.8	1.3	0.7	2.6		1.2	
mg/ℓ	Low	0.7	1.2	0.5[a]	1.0			
Na	High	5.4	4.3	4.3	4.5	4.3	4.3	4.3
mg/ℓ	Low	1.0	3.0	2.3	1.9	1.7	2.1	1.4
K	High	1.8	1.8	1.5	1.6			
mg/ℓ	Low	0.6	0.4[a]	1.1	0.5			
CO_3	High	0	0	0	0	0	0	0
mg/ℓ	Low	0	0	0	0	0	0	0
HCO_3	High	56	48	42	54	43	47	42
mg/ℓ	Low	20	33	26	25	24	26	20
SO_4	High	6.0	2.0	1.0	2.6			
mg/ℓ	Low	0.0	1.0	0.0	1.0			
Cl	High	6.0	1.8	0.4	0.4	1.5	1.3	1.7
mg/ℓ	Low	0.0	0.1	0.2	0.0	0.6	0.0	0.8
NO_3	High	1.5	1.9[a]	1.1	0.7			
mg/ℓ	Low	0.0	0.8	0.8	0.3			
F	High	0.2	0.1					
mg/ℓ	Low	0.0						
B	High	0.1	0.2	0.3	0.4	0.1		
mg/ℓ	Low	0.0	0.0	0.0	0.0	0.0	0.0	
SiO	High	24	21	18	12			
mg/ℓ	Low	10	17	16				
TDS	High	85	67	65				
mg/ℓ	Low	31	50	40	41			
% Na	High	37	23	25				
	Low	9	19	20				
T.H.	High	39	33	29	32	32	32	33
mg/ℓ	Low	16	24	17	19	19	19	14[a]
N.C.H.	High	4	0	0	0			
mg/ℓ	Low	0	0	0	0			
Turbidity JTU	High	30	3	25	3	4	8	30
	Low	0	0	1	1	1	2	3
Coliform	High	2400	60	15	4.6	7		
MPN	Low	0.06	0.23	0.061	0.14			
ABS	High		0.01[a]	0.0	0.0			
mg/ℓ	Low		0.0[a]	0.0	0.0			
As	High		0.00[a]	0.00	0.00			
mg/ℓ	Low		0.00[a]	0.00	0.00			
PO_4	High		0.00	0.00	0.02[a]			
mg/ℓ	Low		0.00	0.00	0.02[a].			

[a] New record high or low.

TABLE XXVI

ANALYSES OF SURFACE WATER, EAST FORK CARSON RIVER

Location: East Fork Carson River near Markleeville

Station: 7G83420.20

Water Year	Prior High-Low Record		63 64	64 65	65 66	66 67	67 68	68 69
EC	High	222	145	137	159	168	148	188
µ mhos	Low	44.0	97	57	90	50	77	54
Temp	High	65	59	52	65	52	75^a	60
°F	Low	32	32	35	32	33	32	32
DO	High	12.0	12.1	12.1	12.3	11.7	10.3	13.2^a
mg/ℓ	Low	7.8	8.5	9.3	8.1	9.6	9.0	8.1
% Sat.	High	103	105	108^a	105	108		
	Low	69	95	97	100	98		
Field	High	8.4	8.3		8.3	8.1	8.2	8.1
pH	Low	6.9	7.3		7.5	7.1	7.3	7.3
Ca	High	16	16	12	16		14	19^a
mg/ℓ	Low	5.2	11	9.4	6.6		7.6	6
Mg	High	8.3	3.2	2.2	6.1		1.4	
mg/ℓ	Low	0.7	1.8	2.1	1.5			
Na	High	14	9.6	9.6	9.6	19	8.9	9.6
mg/ℓ	Low	2.0	6.1	3.3	3.8	2.8	3.8	2.5
K	High	2.5	1.7	1.2	2.0			
mg/ℓ	Low	0.9	0.6^a	0.7	0.9			
CO_3	High	0	1	0	0	0	0	0
mg/ℓ	Low	0	0	0	0	0	0	0
HCO_3	High	116	79	69	88	77	69	83
mg/ℓ	Low	22	49	30	32	27	34	28
SO_4	High	17	8.0	7.0	5.1			
mg/ℓ	Low	1.0	4.0	4.0	3.0			
Cl	High	13	5.5	2.5	2.3	5.1	3.8	3.5
mg/ℓ	Low	0.2	1.5	0.8	0.5	0.8	1.9	1.3
NO_3	High	1.2	1.5^a	1.0	1.0			
mg/ℓ	Low	0.0	0.8	0.9	0.2			
F	High	0.2	0.2					
mg/ℓ	Low	0.0						
B	High	0.4	0.3	0.2	0.5^a	0.3		
mg/ℓ	Low	0.0	0.0	0.0	0.0	0.0	0.0	
SiO_2	High	28	20	21	14			
mg/ℓ	Low	12	19	17				
TDS	High	164	107	101	109			
mg/ℓ	Low	33	65	42	52			
% NA	High	40	29	31				
	Low	11	25	24				
T.H. $CaCO_3$ mg/ℓ	High	94	53	48	65	65	57	80
	Low	19	38	22	22	17	25	21
N.C.H. $CaCO_3$ mg/ℓ	High	2	0	0	0	2		
	Low	0	0	0	0	0		
Turbidity	High	70	5	7	8	25		
JTU	Low	1	1	1	1	2		
Coliform	High	2400	23	2.4	4.6	7	20	60
MPN	Low	< 0.045	0.93	0	0.15		1	6
ABS	High		0.1^a	0.0	0.0			
mg/ℓ	Low		0.0^a	0.0	0.0			
PO_4	High		0.05	0.05	0.15^a			
mg/ℓ	Low		0.05	0.05	0.01^a			
As	High		0.01^a	0.01	0.01			
mg/ℓ	Low		0.00^a	0.00	0.00			

[a] New record high or low.

APPENDIX D

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TABLE XXVII

MONTHLY AVERAGE VALUES OF QUALITY FACTORS IN RECLAIMED WATER (L-III) OBSERVED BY
LCAC DEMONSTRATION GRANT LABORATORY (≅ WEEKLY SAMPLES)

Month	No. of Samples	Influent to Reservoir (mgd)	Cond.* 10^{-6} μ mhos	Cl⁻* mg/l	Unfiltered						Filtered										Ca* mg/l	Alk.* mg/l as $CaCO_3$	pH*
					SS μg/l	VSS μg/l	Org. N μg/l	NH_4 μg/l	Total P μg/l	COD mg/l	Org. N μg/l	NH_4 μg/l	NO_2 μg/l	NO_3 μg/l	Inor. N μg/l	Inor. C mg/l	Total N μg/l	PO_4 μg/l	Total P μg/l	Fe μg/l			
1969 Apr		SEE APPENDIX A																					
May	1		436	27.0	440	600	300	14,050	114	< 1	512	14,900	49	30	14,979	47.8	15,489	110	127	7.0	55.6	195.3	8.2
Jun	3		452	25.5	1,471	1,257	425	17,185	130	35	465	16,554	79	188	17,189	45.4	17,650	100	115	15.0	51.6	189.2	8.0-8.3
Jul	[illegible]		461	28.0	1,066	540	884	13,500	120	21	736	14,190	232	1,692	16,135	46.4	16,907	242	280	6.0	53.2	191.4	7.7-8.8
Aug	3		552	25.6	730	1,436	608	12,275	141	31	706	11,950	72	5,234	15,237	48.9	15,947	36	117	16.7	60.1	196.5	7.8-8.3
Sep	4		515	29.0	948	640	369	15,528	102	42	440	15,222	46	640	15,908	51.8	16,348	70	119	21.0	55.4	211.6	7.7-8.1
Oct	[illegible]		445	28.1	1,403	1,123	408	15,515	153	54	486	15,642	8	108	15,755	61.0	16,243	116	142	16.0	64.0	251.2	7.9-8.5
Nov	1		552	28.4	1,177	1,296	979	14,655	105	24	136	18,613	44	498	19,156	50.4	19,752	48	60	11.3	63.9	204.2	7.4-8.2
Dec	2		508	29.8	1,229	877	714	21,536	156	-	544	20,529	59	108	20,970	44.7	21,564	338	338	5.0	56.4	178.8	7.8
1970 Jan	1		616	33.0	1,710	1,190	1,048	25,170	172	26	1,000	26,270	4	31	27,274	59.0	24,265	60	71	5.0	70.0	246.0	8.0
Feb	2		565	26.1	1,313	1,420	750	26,975	125	10	752	20,359	12	68	20,437	61.0	21,196	96	116	4.0	64.6	254.0	8.1
Mar	2		564	21.6	1,043	1,597	516	21,177	175	15	782	21,100	9	136	21,245	77.1	22,087	115	129	12.0	61.2	241.4	8.0-8.3
Total Mean			524	27.4	1,204	1,084	723	18,160	162	22	647	17,942	52	612	18,568	52.1	19,515	126	148	11.3	57.6	215.0	7.4-8.8
Std. Dev.			55	3.2	349	308	164	5,815	30	14	176	4,154	79	997	3,728	6.3	4,101	87	80	5.9	9.6	27.0	

*Analyses made on filtered samples.

TABLE XXVIII

MONTHLY AVERAGE VALUES OF QUALITY FACTORS IN INDIAN CREEK RESERVOIR WATER (C) OBSERVED BY
STAC DEMONSTRATION GRANT LABORATORY (≃ WEEKLY SAMPLES)

Month	No. of Samples	Effluent to Reservoir (mgd)	Cond. 10^{-6} μ mhos[a]	Cl^-[a] mg/l	Unfiltered						Filtered										Ca[a] mg/l	Alk.[a] mg/l as $CaCO_3$	pH[a]
					SS μg/l	VSS μg/l	Org. N μg/l	NH_4 μg/l	Total P μg/l	COD mg/l	Org. N μg/l	NH_4 μg/l	NO_2 μg/l	NO_3 μg/l	Inor. N μg/l	Inor. C mg/l	Total N μg/l	PO_4 μg/l	Total P μg/l	Fe μg/l			
1970 Apr		SEE APPENDIX A																					
May	1		298	13.3	1,448	646	906	5,290	44	8	500	4,200	282	918	5,400	27.1	6,000	63	78	16	15.5	108.5	7.8
Jun	2		308	13.6	1,257	4,140	1,002	5,791	43	33	547	3,285	96	982	4,380	25.1	5,207	14	23	24	35.5	104.7	8.0-8.1
Jul	3		327	14.5	1,900	1,508	1,021	5,130	48	42	1,065	5,070	119	1,877	5,066	26.1	6,131	30	30	12	36.2	107.7	7.9-8.2
Aug	3		348	14.5	4,312	5,013	1,066	5,140	38	25	440	2,442	247	2,625	5,362	25.9	6,352	8	27	3	36.7	107.7	8.1-8.3
Sep	4		364	21.2	2,989	1,867	2,144	5,701	32	11	1,021	3,648	268	2,425	6,301	29.0	7,322	43	65	15	50.9	119.4	7.7-8.1
Oct	5		392	23.2	3,377	1,805	922	2,710	77	56	922	2,885	337	3,036	6,218	32.1	7,140	48	75	16	42.5	133.8	8.2
Nov	3		390	26.1	1,620	750	821	2,540	70	18	924	2,981	122	3,071	6,174	31.4	7,098	53	67	6	46.8	129.1	7.9-8.2
Dec	2		395	24.7	1,645	675	1,020	1,445	76	33	1,008	4,370	186	3,610	8,360	33.6	9,368	54	66	2	49.6	134.6	7.9
1971 Jan	1		405	26.1	1,510	550	715	2,885	66	26	725	3,420	110	3,486	7,016	33.7	7,739	51	60	2	49.6	140.3	8.1
Feb	2		389	20.4	7,545	2,750	1,077	2,400	70	43	890	3,638	146	3,648	7,432	30.5	8,322	40	51	4	45.9	126.8	8.0-8.1
Mar	3		366	18.2	4,183	7,377	1,512	5,308	35	22	1,005	3,795	105	4,068	7,966	31.0	8,971	6	20	1	48.6	129.4	8.3-8.5
Total Mean			354	21.6	4,083	2,245	1,206	3,448	52	25	909	3,457	238	2,657	6,334	29.6	7,241	37	51	9	41.6	122.0	7.7-8.5
Std. Dev.			37	3.4	2,858	2,111	387	1,364	20	12	140	616	105	1,134	1,254	3.1	1,291	20	22	8	10.4	12.9	

[a]Analyses made on filtered samples.

TABLE XXIX

MONTHLY AVERAGE VALUES OF QUALITY FACTORS IN WATER DISCHARGED FROM INDIAN CREEK RESERVOIR (a)
REPORTED BY [illegible] DEMONSTRATION GRANT LABORATORY (≥ WEEKLY SAMPLES)

Month	No. of Samples	Volume of Discharge [illegible]	Cond.ª [illegible]	[illegible]ª	Unfiltered SS µg/l	VSS µg/l	Org. N µg/l	NH₄ µg/l	Total P µg/l	COD mg/l	Filtered Org. N µg/l	NH₄ µg/l	NO₂ µg/l	NO₃ µg/l	Inorg. N µg/l	Inorg. C mg/l	Total D µg/l	PO₄ µg/l	Total P µg/l	Fe µg/l	Caª mg/l	Alk.ª mg/l as CaCO₃	pHª
[illegible]																							
Apr	[illegible]	SEE APPENDIX A	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.1-8.4
May	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0
Jun	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Jul	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Aug	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sep	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	7.9-8.1
Oct	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]	13	41.8	129.1	8.1-8.2
Nov	4		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49	[illegible]	8	48.4	127.1	7.9-8.1
Dec	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52	[illegible]	8	[illegible]	132.8	8.0
[illegible]																							
Jan	1		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	8.1
Feb	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]	8.0
Mar	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]
Total																							
Mean			[illegible]	28.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	[illegible]	121.2	[illegible]
Std. Dev.			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92	[illegible]	9	[illegible]	10.7	

ªAnalyses made on filtered samples.

TABLE XXX

MONTHLY AVERAGE VALUES OF QUALITY FACTORS IN RECLAIMED WATER (L-III) OBSERVED BY STUD (24-HR COMPOSITE SAMPLES)

Month	No. of Samples	Total Volume of Water (mil gal)		Cond.	Cl^-	SS	VSS	Org. N	NH_3	P	COD	Org. N	NH_3	NO_2	NO_3	Total N (Ino.)	PO_4	Total P	Fe	Ca	Alk. mg/ℓ as $CaCO_3$	pH
		Influent to Reservoir (L-III)	Released from Reservoir (P)	μ mhos	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	μg/ℓ	mg/ℓ		
1969																						
Apr	22	0	76.8		21.0						9.5		-	290	1,000	-	250				219	
May		0	65.9		22.1						4.7		-	100	590	-	280				223	
Jun	21	0	81.0		17.2						7.2		14,000	190	900	15,090	200				206	
Jul	22	0	75.9		21.8						11.1		12,100	2,360	2,450	16,910	260				173	
Aug	21	96.0	82.5		25.6						8.5		-	260	1,860	-	120				214	
Sep	21	62.5	61.9		26.2						8.1		14,200	310	1,100	15,610	80				200	
Oct	22	0	56.0		23.1						5.7		15,000	260	1,100	16,360	130				269	
Nov	21	0	50.2		26.4						8.7		17,100	120	1,100	18,320	80				230	
Dec	23	0	94.0		25.0						9.8		19,400	60	300	19,760	170				215	
1970																						
Jan	21	0	87.0		25.0						7.5		16,400	130	600	17,130	280				194	
Feb	19	0	65.5		22.0						8.9		19,800	30	400	20,230	200				211	
Mar																						
Mean			72.2		22.8						8.2		16,000	374	1,018	17,426	175				214	
Std. Dev.			13.7		2.6						1.8		2,694	666	653	1,865	93				24	

APPENDIX E

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TABLE XXXI

BIOMASS MEASUREMENTS[1] (FLASK ASSAY) - INDIAN CREEK RESERVOIR

Date of Sampling	Sample Type	Concentration (% of Sample) %	Test Cell Inoculum	Counting Method	Detention Time, d				
					1 day	3 day	5 day		
					Counts cell no./mm³	Counts cell no./mm³	Counts cell no./mm³	Suspended Solids mg/l	pH
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE XXXII

MAXIMUM GROWTH RATES AND CELL CONCENTRATIONS ATTAINED IN FIVE-DAY FLASK ASSAYS OF INFLUENT, IMPOUNDED, AND DISCHARGED WATER AT INDIAN CREEK RESERVOIR

Date	Sample	Conc. %	$\hat{\mu}_{b,l}$	Corr. Coef.	$\hat{\mu}_b$	C_v %	$\hat{X}_m$	C_v %	SS mg/ℓ
1968									
10- 3[a]	ICR A	50	.713	.988	.8610	6.5	744.	17.5	24.25
	ICR B	50	.614	.982	.7642	10.7	435.	20.4	11.64
11- 4	ICR A	50	.656	.994	.7533	8.1	480.	12.4	16.28
		100	.551	.968	.6951	15.1	265.	8.8	23.44
	ICR B	50	.696	.971	.9022	15.9	532.	29.8	19.68
		100	.649	.973	.8158	21.1	445.	25.6	24.31
1969									
4- 1	ICR A	1	.307	.914	.4814	16.7	151.	9.1	6.06
		10	.544	.938	.8550	7.4	345.	23.0	15.71
		100	.729	.986	.8826	12.0	659.	14.9	30.00
	ICR B	1	.288	.985	.3362	7.3	122.	9.1	5.06
		10	.437	.943	.6628	14.0	222.	18.6	10.41
		100	.685	.991	.7817	14.4	645.	5.9	23.43
4-28	ICR A	1	.304	.958	.5569	12.0	210.	21.0	7.15
		10	.355	.905	.6036	10.3	203.	22.5	8.29
		100	.371	.943	.5409	9.7	216.	21.1	9.40
	ICR B	1	.315	.861	.5852	20.0	180.	22.3	7.37
		10	.277	.946	.3772	40.3	233.6	7.2	9.44
		100	.396	.971	.4426	21.4	324	16.1	13.75
5-29	ICR A	1	.049	.748	.2079	31.0	60.	6.2	2.31
		10	.372	.953	.4611	22.4	148.	10.0	5.88
		100	.638	.975	.7392	12.4	467.	19.6	20.67
	ICR B	1	.168	.875	.2402	36.3	71.	18.3	2.70
		10	.388	.952	.5357	21.9	153.	20.3	7.24
		100	.609	.922	.7579	24.2	405.	52.4	21.09
	ICR C	1	.187	.901	.2517	31.6	85.	29.2	3.28
		10	.529	.945	.8086	13.3	237.	10.9	7.57
		100	.850	.988	1.0406	5.9	1061.	9.3	28.59
	L-III	1	.153	.904	.2331	28.3	76.	12.2	3.76
		10	.490	.929	.7774	10.0	246.	25.4	10.74
		100	.157	.826	.2669	33.2	61.	12.3	3.86
6- 4	ICR B	1	.270	.847	.3728	36.7	96.	21.8	4.34
		10	.567	.963	.8133	17.3	229.	2.8	8.70
		100	.727	.997	.9098	5.7	552.	7.4	17.68
	ICR C	1	.256	.913	.3782	29.3	85.	4.4	3.06
		10	.194	.824	.2677	18.8	70.	8.9	3.42
		100	.253	.949	.3398	14.7	95.	15.2	3.38
	L-III	1	.321	.934	.4841	19.9	98.	14.2	4.28
		10	.640	.972	.7862	20.6	312.	33.6	11.81
		100	.168	.744	.2973	43.8	32.	10.0	3.22
6-19	ICR B	1	.388	.845	.6900	26.6	127.	4.6	3.80
		10	.499	.962	.6998	19.3	263.	11.7	8.79
		100	.773	.988	.8906	5.7	862.	21.7	27.30
	ICR C	1	.199	.894	.5130	17.9	128.	15.5	4.22
		10	.347	.880	.6459	15.9	149.	14.2	5.56
		100	.298	.879	.3546	10.4	129.	17.8	6.29
	L-III	1	.287	.937	.4333	20.5	126.	12.5	4.31
		10	.224	.864	.3700	20.8	88.	15.6	4.18
		100	.082	.710	.1388	70.6	41.	17.3	3.08
6-24	IRC B	1	.096	.637	.2240	47.9	87.	29.4	4.41
		10	.298	.855	.4306	15.0	220.	54.0	10.17
		100	.521	.985	.6161	20.0	344.	10.9	15.33
	IRC C	1	.098	.693	.1665	52.6	90.	23.4	4.45
		10	.242	.884	.4246	24.3	160.	11.9	6.14
		100	.274	.875	.5027	19.4	164.	10.4	7.10
	L-III	1	.110	.729	.2277	39.9	90.	18.6	4.68
		10	.394	.945	.4311	20.8	209.	34.3	10.48
		100	.058	.521	.1272	57.5	51.	14.7	3.32

TABLE XXXII (Continued)

Date	Sample	Conc. %	$\hat{\mu}_{b\ell}$	Corr. Coef.	$\hat{\mu}_b$	C_v %	$\hat{X}_5$	C_v %	SS mg/ℓ
7- 1	ICR B	1	.094	.647	.1802	78.1	66.	17.7	2.21
		10	.044	.638	.1058	27.8	63.	9.5	2.67
		100	.069	.702	.1388	35.0	75.	13.3	5.67
	ICR C	1	.082	.778	.1481	49.4	71.	12.7	2.58
		10	.042	.434	.1221	58.1	68.	13.1	3.52
		100	.181	.906	.2651	27.6	115.	19.7	7.19
	L-III	1	.020	.243	.1093	91.4	65.	9.1	2.68
		10	.116	.616	.3305	47.6	67.	3.4	4.34
		100	.011	.119	.0941	113.6	52.	17.7	4.60
7-10[b]	ICR B	1	.155	.954	.1862	5.5	228.4	9.7	5.43
		10	.287	.957	.4279	14.1	396.3	3.2	11.21
		100	.482	.993	.4936	3.2	773.8	13.3	24.79
	ICR C	1	.121	.982	.1321	6.7	205.8	3.8	5.42
		10	.090	.945	.1349	13.6	187.	2.0	6.05
		100	.061	.271	.0704	41.9	111.2	31.5	3.67
	L-III	1	.113	.963	.1390	17.1	218.6	2.9	7.05
		10	.204	.912	.3130	17.0	304.8	17.0	9.24
		100	.030	.607	.0484	40.5	118.	10.2	3.75
7-17	ICR B	1	.130	.929	.1667	36.5	257.3	16.9	6.45
		10	.208	.981	.2697	3.9	364.6	4.3	10.78
		100	.240	.461	.5757	42.7	693.4	44.9	56.00
	ICR C	1	.107	.961	.1479	17.8	239.7	4.3	6.53
		10	.104	.966	.1317	11.1	241.6	4.1	7.41
		100	.155	.930	.2523	5.9	332.	4.0	9.89
	L-III	1	.251	.951	.3899	4.7	454.	2.3	11.16
		10	.429	.936	.6966	3.9	826.8	10.9	17.32
		100	.114	.959	.1337	33.2	172.4	9.8	7.33
7-22	ICR B	1	.376	.942	.5861	13.0	272.7	9.7	4.61
		10	.657	.982	.8418	8.2	842.2	14.0	11.96
		100	.424	.973	.5774	5.4	339.2	11.9	8.49
	ICR C	1	.387	.937	.6323	6.0	278.6	2.9	4.40
		10	.609	.966	.8484	14.5	646.8	10.1	12.61
		100	.106	.869	.1884	9.0	95.7	7.3	3.53
	L-III	1	.493	.972	.6646	10.2	444.2	15.6	6.00
		10	.258	.951	.3981	7.3	175.	5.4	3.19
		100	-.020	-.600	.0069	156.5	57.6	3.5	1.07
7-29	ICR B	1	.082	.918	.1261	21.8	169.7	4.8	3.47
		10	.315	.980	.4234	5.1	357.2	2.4	10.05
		100	.603	.973	.8281	4.6	1262.4	12.7	34.45
	ICR C	1	.081	.931	.1180	39.8	160.7	2.1	3.29
		10	.062	.910	.0858	24.1	157.8	2.1	2.92
		100	.212	.948	.3243	8.1	250.	5.4	9.26
	L-III	1	.078	.970	.1001	14.3	151.4	3.2	2.21
		10	.092	.890	.1163	32.9	128.6	10.4	1.27
		100	.037	.820	.0619	44.3	101.7	2.7	1.87
8- 5	ICR B	1	.222	.914	.3435	14.9	130.4	6.1	3.83
		10	.521	.985	.6735	3.3	414.	2.1	8.98
		100	.672	.984	.8624	4.4	759.	8.8	14.25
	ICR C	1	.161	.962	.2323	10.2	99.	3.2	3.24
		10	.210	.976	.2812	2.7	121.8	4.6	3.13
		100	.286	.852	.4166	43.3	177.9	4.3	4.62
	L-III	1	.196	.945	.3073	5.4	114.6	3.1	2.82
		10	.007	.274	.0334	38.9	51.5	3.9	0.44
		100	.036	.546	.0919	26.7	58.2	13.9	0.98
8-12	ICR B	1	.189	.954	.2848	5.1	143.3	4.8	-
		10	.541	.985	.6953	4.2	523.8	8.2	10.00
		100	.711	.975	.9658	3.6	1019.6	16.7	25.71
	ICR C	1	.067	.829	.1343	22.3	83.3	1.8	3.03
		10	.091	.842	.1908	9.5	92.2	2.8	4.44
		100	.094	.799	.2076	15.0	80.8	5.7	3.02
	L-III	1	.105	.923	.1614	5.9	92.8	8.9	3.08
		10	.299	.979	.3905	6.5	201.4	3.0	3.92
		100	-.028	-.485	.0447	92.4	48.8	3.1	1.95

TABLE XXXII (Continued)

Date	Sample	Conc. %	$\hat{\mu}_{b\ell}$	Corr. Coef.	$\hat{\mu}_b$	C_v %	$\hat{X}_g$	C_v %	SS mg/ℓ
8-19	ICR B	1	.187	.726	.3853	56.2	167.5	20.4	
		10	.572	.952	.8208	19.3	773.6	21.8	
		100	.977	.982	1.2644	12.1	5455.	6.9	
	ICR C	1	.102	.633	.2571	59.9	117.7	11.4	
		10	.113	.806	.2224	36.5	128.8	8.1	
		100	.094	.735	.1905	35.2	120.6	14.2	
	L-III	1	.152	.938	.2215	26.6	152.6	6.9	
		10	.375	.939	.4653	27.9	410.5	34.2	
		100	.010	.161	.0751	73.6	80.3	10.5	
9- 2	ICR B	1	.218	.920	.3576	14.2	112.9	11.7	
		10	.246	.929	.3859	16.7	142.3	9.0	
		100	.252	.942	.2899	15.1	430.2	21.8	
	ICR C	1	.253	.954	.3367	18.0	180.8	10.4	
		10	.137	.568	.1795	51.3	187.3	36.4	
		100	.153	.911	.1988	43.5	291.6	8.7	
	L-III	1	.231	.928	.3685	23.3	146.2	5.3	
		10	.184	.821	.2306	53.5	150.2	25.3	
		100	.101	.811	.1959	29.4	71.	7.0	
9-10^c	ICR B	1	.169	.631	.3584	36.1	160.5	49.0	0.92
		10	.377	.956	.5421	12.4	318.6	17.0	2.72
		100	.572	.982	.7066	16.2	699.6	11.5	15.37
	ICR C	1	.116	.707	.2222	56.4	119.	21.3	1.30
		10	.331	.912	.4154	31.3	277.7	36.9	3.37
		100	.249	.585	.8251	11.2	168.	16.0	7.97
	L-III	1	.313	.831	.5723	32.8	266.6	30.2	2.06
		10	.280	.830	.5440	13.9	195.	30.6	1.47
		100	-.026	-.176	.0692	15.0	66.6	33.2	0.41
9-16	ICR B	1	.296	.810	.5862	26.8	239.4	28.1	3.28
		10	.227	.668	.5710	8.2	164.7	53.6	3.82
		100	.981	.947	1.4498	18.7	449.2	18.9	34.10
	ICR C	1	.265	.780	.6024	14.6	210.	22.1	2.07
		10	.592	.924	.9643	12.8	713.	23.3	4.50
		100	1.007	.957	1.5081	9.4	3906.	4.4	25.56
	L-III	1	.390	.803	.7523	26.4	356.5	35.0	3.95
		10	.138	.642	.3784	33.9	128.8	14.9	1.38
		100	.056	.456	.0927	121.7	94.9	27.6	0.15
9-25	ICR B	1	.149	.577	.1712	99.3	147.5	45.6	1.29
		10	.615	.853	.8450	35.5	896.	80.5	5.71
		100	1.182	.929	1.9552	5.6	6988.	5.5	42.11
	ICR C	1	.087	.410	.1554	103.2	101.1	38.2	1.66
		10	.310	.633	.5968	47.8	243.	60.2	4.51
		100	1.199	.962	1.7778	3.7	589.4	6.8	41.32
	L-III	1	.345	.816	.7402	8.0	308.6	19.9	3.13
		10	.544	.913	.9124	11.4	613.2	24.7	4.98
		100	.041	.415	.1013	44.1	62.8	26.9	2.04
10- 2	ICR B	1	.048	.492	.1539	37.4	66.1	5.9	7.48
		10	.302	.728	.4875	37.0	162.2	42.4	4.83
		100	1.249	.987	1.5265	8.6	5720.	7.7	28.48
	ICR C	1	.062	.425	.1888	23.3	65.0	7.2	2.86
		10	.204	.795	.3554	31.5	95.0	31.8	4.94
		100	1.092	.995	1.2168	7.7	549.4	6.2	24.33
	L-III	1	.483	.928	.8061	7.3	326.9	12.1	3.61
		10	.278	.619	.4344	76.3	153.2	64.4	2.49
		100	-.126	-.824	-.0234	-225.6	27.2	14.0	1.73
10-16	ICR B	1	.066	.776	.1210	69.0	134.3	4.8	4.32
		10	.180	.898	.3237	12.8	169.4	4.1	6.86
		100	.261	.806	.5838	7.7	176.9	8.2	35.70
	ICR C	1	.086	.745	.2069	4.3	142.	6.1	3.61
		10	.112	.716	.2810	23.1	170.6	2.6	6.19
		100	.209	.711	.5511	11.4	154.5	8.8	26.81
	L-III	1	.095	.713	.2523	8.0	145.3	3.0	5.36
		10	.097	.756	.1740	24.4	66.	20.5	4.85
		100	-.043	-.132	.5135	9.7	35.6	7.3	0.64

TABLE XXXII (Continued)

Date	Sample	Conc. %	$\hat{\mu}_{b\ell}$	Corr. Coef.	$\hat{\mu}_b$	C_v %	$\hat{X}_s$	C_v %	SS mg/ℓ
10-16	ICR B	1	.525	.827	1.0744	20.8	611.2	28.1	4.06
		10	.743	.902	1.2501	9.5	1358.	12.2	5.41
		100	1.072	.948	1.5805	13.9	5357.5	23.2	4.43
	ICR C	1	.25	.915	.8652	12.9	608.2	25.6	4.40
		10	.686	.921	1.1797	7.0	1219.2	4.7	6.88
		100	1.028	.981	1.3619	7.0	4236.	5.0	4.88
	L-III	1	.623	.917	1.0720	7.9	871.	21.0	5.22
		10	.496	.941	.5700	19.4	572.8	58.3	1.29
		100	-.013	-.151	.0778	117.2	71.9	6.7	0.95
10-24	ICR P	1	.303	.812	.4595	6.9	249.8	26.7	
		10	.263	.903	.3874	25.1	229.8	13.1	
		100	.057	.570	.1336	54.6	449.6	17.3	
	ICR C	1	.373	.957	.5148	10.5	191.	11.5	
		10	.259	.937	.2986	27.2	214.0	12.1	
		100	.170	.917	.2362	29.2	255.1	12.8	
	L-III	1	.281	.905	.4263	25.2	218.5	10.2	
		10	.271	.899	.4000	37.4	196.	7.4	
		100	.155	.775	.2362	49.1	100.5	18.2	
10-30	ICR B	1	.028	.481	.0656	32.3	95.	11.7	
		10	.139	.945	.1759	23.1	141.4	9.3	
		100	.107	.802	.1800	43.6	187.	10.2	
	ICR C	1	.069	.738	.1358	46.8	116.	12.7	
		10	.239	.885	.3764	22.6	209.4	26.0	
		100	.385	.973	.5308	9.4	766.4	8.8	
	L-III	1	.078	.476	.1983	63.4	122.7	24.9	
		10	.144	.709	.2090	60.3	155.1	34.0	
		100	-.016	-.220	.0744	57.3	187.7	9.5	
11-15	ICR B	1	.152	.806	.2840	32.2	215.6	9.4	4.02
		10	.179	.954	.1998	17.1	315.	12.6	5.17
		100	.516	.982	.6575	0.4	1645.2	15.9	45.46
	ICR C	1	.118	.835	.1423	28.0	216.6	12.2	3.26
		10	.196	.976	.2312	15.2	273.8	5.3	2.63
		100	.474	.989	.5470	3.0	1485.6	14.6	29.59
	L-III	1	.120	.920	.1493	14.3	210.5	10.3	3.98
		10	.108	.756	.1498	66.8	292.1	18.7	3.46
		100	.089	.750	.1551	17.2	1120.	7.4	3.44
11-19	ICR B	1	.131	.829	.2142	26.7	196.8	6.8	2.84
		10	.150	.898	.2074	18.4	185.8	7.6	2.71
		100	.608	.979	.7184	20.0	1387.6	5.5	19.54
	ICR C	1	.014	.186	.0874	42.0	160.7	8.6	2.87
		10	.216	.976	.2658	18.1	252.8	6.1	4.77
		100	.596	.987	.7103	15.8	1277.8	2.3	20.25
	L-III	1	.108	.812	.1518	54.1	211.8	13.2	2.87
		10	.135	.867	.1676	29.6	184.2	10.7	2.95
		100	.144	.454	.2228	79.6	273.2	7.9	-
11-26	ICR B	1	.176	.955	.2475	35.6	253.6	11.5	3.30
		10	.168	.965	.2218	24.8	216.6	3.6	5.00
		100	.481	.910	.8527	8.3	1188.4	6.6	11.25
	ICR C	1	.126	.916	.1665	5.0	188.	13.9	3.90
		10	.166	.978	.1775	5.6	234.7	2.8	4.42
		100	.597	.992	.4220	10.9	1194.5	11.7	10.90
	L-III	1	.156	.955	.1751	21.9	197.8	7.2	3.60
		10	.196	.986	.2217	19.0	214.1	5.0	4.17
		100	.067	.705	.1484	58.8	161.	3.5	2.17
12- 3	ICR B	1	.115	.845	.1327	56.6	204.9	17.1	3.48
		10	.201	.968	.2508	8.2	268.0	3.4	2.92
		100	.525	.987	.6585	4.7	804.8	5.6	19.23
	ICR C	1	.096	.718	.1388	32.0	222.6	17.9	2.12
		10	.186	.925	.2596	22.0	296.2	15.1	3.21
		100	.755	.981	1.0107	2.1	2156.	1.4	17.13
	L-III	1	.171	.958	.2084	25.4	228.8	4.1	2.58
		10	.255	.949	.3110	18.0	281.3	6.8	3.81
		100	.900	.906	1.6228	2.6			2.33

TABLE XXXII (Continued)

Date	Sample	Conc. %	$\hat{\mu}_{bl}$	Corr. Coef.	$\hat{\mu}_b$	C_v %	$\hat{X}_s$	C_v %	SS mg/l
12-16	ICR B	1	.147	.842	.2319	20.1	88.4	19.3	0.38
		10	.091	.696	.2159	30.0	78.2	10.4	1.30
		100	.269	.830	.3354	44.6	152.6	37.0	3.32
	ICR C	1	.073	.711	.1558	45.7	65.6	10.4	0.52
		10	.117	.872	.2037	23.4	88.2	4.4	1.28
		100	.329	.976	.4035	16.9	183.2	16.3	3.82
	L-III	1	.126	.872	.2035	33.6	85.8	9.9	0.75
		10	.139	.819	.2508	21.7	91.3	14.0	1.06
		100	.123	.908	.1626	22.4	73.2	15.2	0.97

[a] Test alga *S. gracile*, hand counted during period 10-3-1968 to 7-1-1969.

[b] Test alga *S. capricornutum*, counted by Coulter Counter during period 7-10-1969 to 12-16-1969.

[c] Test alga culture of *S. capricornutum* contaminated by *Chlorella* sp. during period 9-10-1969 to 10-16-1969.

APPENDIX F

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(PRELIMINARY)

BENTHIC INVERTEBRATES
OF
INDIAN CREEK RESERVOIR

by

W. Arthur Noble

ABSTRACT

Seventeen Ekman Dredge samples from Indian Creek Reservoir October 1969, yielded a total of 1,967 midge larvae, 98% of which were forms highly tolerant of low oxygen conditions. The moderately high midge populations (464/sq ft), very low species diversity (5 genera), and dominance by pollution tolerant forms [Chironomus (Chironomus), Procladius and Glyptotendipes] is symptomatic of oxygen depletion in the bottom sediments and lower water strata. Dredging also yielded a high concentration of Cladocera eggs (3,142/sq ft), indication that a dense plankton "bloom" occurred during the previous summer. Qualitative samples from rocks along the shoreline yielded 1,050 midge larvae, 85% of which were a form highly tolerant of low oxygen conditions (Glyptotendipes).

U. S. Department of the Interior
Federal Water Pollution Control Administration
Pacific Southwest Region
Alameda, California

February 1970

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I. INTRODUCTION

General

A benthic invertebrate survey was conducted of Indian Creek Reservoir, October 8-9, 1969, as part of the "Eutrophication of Surface Waters – Lake Tahoe (Indian Creek Reservoir)" project, by the Lake Tahoe Area Council (FWPCA Grant No. 16010 DNY). Technical assistance was provided by FWPCA personnel on this initial survey.

Indian Creek Reservoir, located near the town of Woodfords, Alpine County,* California, has a capacity of 3,225 acre-ft, a surface area of 165 acres, and a maximum depth of 56 ft. The reservoir was initially built during the winter of 1967, and since April 1968, has received the tertiary treated effluent from the South Tahoe Public Utilities District Water Reclamation Plant.

Acknowledgments

Field sampling was done by W. Arthur Noble, Dr. Donald B. Porcella and Dr. Gordon L. Dugan of the Sanitary Engineering Research Laboratory, University of California at Berkeley, who also provided transportation, boat and equipment. Benthic samples were picked, sorted and identified at the California-Nevada Basin Laboratory at Alameda.

II. METHODS

Field Sampling

Nine stations were visited; eight located in the reservoir, and one located in Indian Creek downstream of the reservoir (Figure 2).** Station 1 through 7 were sampled by Ekman Dredge, with jaws that close on a 6 x 6 in. surface area. Dredged material was screened through a US 30 sieve (0.589 mm openings), the residue placed in jars and preserved in 10% formalin. Station 8 was sampled by scrubbing rocks, which were obtained from 2 in. to 2 ft depths, in a bucket of water. The residue was screened through a US 30 sieve and preserved in 10% formalin. Station 9 was sampled by scrubbing rocks from the stream bed, and by sieving mud from the stream bottom. The residue was screened through a US 30 sieve and preserved in 10% formalin. A total of 19 samples were obtained from the lake and stream. Listed in Table 1 are the sampling methods, location, substrate type and number of samples for each station.

TABLE 1. SAMPLES OBTAINED

Station No.	Type of Sample	Location	Substrate	No. of Samples
1	Ekman Dredge	Lake bottom	Silty-clay	3
2	Ekman Dredge	Lake bottom	Silty-clay	3
3	Ekman Dredge	Lake bottom	Silty-clay	3
4	Ekman Dredge	Lake bottom	Silty-clay	3
5	Ekman Dredge	Lake bottom	Silty-clay	3
6	Ekman Dredge	Lake bottom	Silty-clay	1
7	Ekman Dredge	Lake bottom	Silty-clay	1
8	Rock scrubbing	Shoreline	Rocks	1
9	Rock scrubbing and mud	Stream	Rocks and mud	1

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*See Figure 1, page 6, Chapter II.

**See Figure 6, page 16, Chapter III.

Laboratory Methods

Benthic collections were rinsed in a US 50 sieve (0.295 mm openings) and then spread in a shallow white tray. All invertebrate organisms were picked from the debris, sorted as to kind, placed in individual labeled vials of 70% alcohol, and taped together to await identification. Samples were first identified, counted and recorded from each individual sample. Then all samples were combined, and the organisms grouped according to taxa and rechecked for correct identification.

III. RESULTS AND DISCUSSION

Lake Bottom

The results of Benthic invertebrates obtained by Ekman Dredge are presented in the Appendix and summarized in Tables 2-4.

TABLE 2. BENTHIC INVERTEBRATES FROM INDIAN CREEK RESERVOIR
October 9, 1969
(Average Number of Organisms per Ekman Dredge)

Organisms	Stations						
	1	2	3	4	5	6	7
Crustacea							
Cladocera (water fleas)							
Ephippia (winter eggs)*	2163	2427	2376	1997	1133	616	2640
Insecta							
Diptera (flies)							
Chironomidae (true midges)							
Tanypodinae							
Procladius sp.	28	65	60	41	22	45	26
Chironominae							
Chironomus (*Chironomus*) sp.	74	80	72	117	37	20	7
Chironomus (*Cryptochironomus*) sp.	-	-	-	-	-	-	1
Glyptotendipes sp.	.7	2	.3	2	4	5	5
Tanytarsus sp.	-	-	.3	1	4	20	5
Unidentified pupae	-	-	-	-	.3	1	-
Average No. of Organisms per Dredge*	103	147	132	162	67	91	44
Number of Dredges Obtained	3	3	3	3	3	1	1

*Ephippia not included in total averages.

TABLE 3. BENTHIC INVERTEBRATES FROM INDIAN CREEK RESERVOIR
October 9, 1970
(Percent Occurrence of Organisms per Ekman Dredge)

Organism	Stations						
	1	2	3	4	5	6	7
Insecta							
Diptera (flies)							
Chironomidae (true midges)							
Tanypodinae							
Procladius sp.	27.6	44.3	45.4	25.4	32.3	49.4	59.0
Chironominae							
Chironomus (Chironomus) sp.	71.8	54.1	54.2	72.6	55.2	22.0	16.0
Chironomus (Cryptochironomus) sp.	-	-	-	-	-	-	2.2
Glyptotendipes sp.	.6	1.6	.2	1.4	5.5	5.5	11.4
Tanytarsus sp.	-	-	.2	.6	6.5	22.0	11.4
Unidentified pupae	-	-	-	-	.5	1.1	-
Average % of Organisms per Dredge	103	147	132	162	67	91	44
Number of Dredges Obtained	3	3	3	3	3	1	1

TABLE 4. BENTHIC INVERTEBRATES FROM INDIAN CREEK RESERVOIR
October 9, 1970
(Percent Occurrence of Organisms From All Ekman Dredges)

Organism	Percent
Insecta	
Diptera (flies)	
Chironomidae (true midges)	
Tanypodinae	
Procladius sp.	36.6
Chironominae	
Chironomus (Chironomus) sp.	59.2
Chironomus (Cryptochironomus) sp.	.05
Glyptotendipes sp.	2.0
Tanytarsus sp.	2.1
Unidentified pupae	.1

The above tables show a relatively uniform distribution, with a uniformly low species diversity. Only five different taxa were obtained, all of which were midges. Dominant forms were Chironomus (Chironomus) and Procladius, together totaling 96.8% of all organisms retrieved. Water quality permitting, this lake could support a dozen or more different genera of midges alone (2,3). Particularly noticeable by their absence were oligochaetes, flatworms, leeches, snails, amphipods and clams. These organisms may not yet have been transported into the basin by migrating birds and mammals.

The 17 dredge samples represent a total of 4.25 sq ft of lake bottom. Since the lake covered 132* acres at the time of sampling or 5,750,000* sq ft, the area sampled is less than 1/1,353,000* of the lake benthal area. Although the newness of the reservoir may not have allowed some slower colonizing forms time to migrate and multiply sufficiently to be represented in dredge samples, it is likely that water quality and bottom substrate has prohibited many forms from developing.

Averaging all dredge samples yields a standing crop of 464 midge larvae per sq ft. Assuming a uniform density of 464/sq ft, and a benthal area of 5,750,000* sq ft, yields a total midge population of 2.7(-)* billion. This figure is more conjecture and the concentration not unusually high for a lake.

Particularly significant, is that three of the midge types obtained Chironomus (Chironomus), Procladius and Glyptotendipes, have physiological properties which enable them to live in low oxygen, and sometimes for several weeks in anoxic mud (see Figures 3-5). Furthermore, these three taxa amounted to 98% of all the organisms obtained. Therefore, it appears that the benthal region restricts the midge populations primarily to low oxygen resistant types, and indicates the anoxic nature of the bottom sediments and overlying waters.

Very high numbers of ephippia (winter eggs of Cladocera) were obtained, averaging 3,142/sq ft, or approximately 19.6* billion in the lake bottom. This egg density indicates that extremely high concentrations of adult Cladocera (zooplankters) existed during the summer months, as well as an extremely high concentration of algae, bacteria and detritus that was necessary to support them.

The nature and amount of substrate retrieved by dredging, indicates that the lake bottom contains a thin layer of silty-clay, with a sludge-like deposit around the sewage effluent discharge area. The amount of substrate retrieved varied from 0.5 to 1.2 liters, with a mean of 0.8 liters per dredge.

Lake Shoreline

The results of scrubbing rocks in shoreline shallows, presented in the Appendix and summarized in Table 5, show low species diversity. The dominant form was the low oxygen tolerant midge larvae Glyptotendipes. It comprised 85% of all the organisms obtained. This is particularly significant since the shallows readily receives gas exchange through the surface interface promoted by wave action (4). A healthy lakeshore normally supports a highly diverse population of midges (as well as other kinds of animals), and few, if any, that are highly tolerant of low oxygen conditions (2,3).

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*Author's original estimate based on reservoir full at 165 acres, corrected by Demonstration Grant Project editor to correspond to 48.75 ft depth of water in reservoir on October 8, 1969.

TABLE 5. BENTHIC INVERTEBRATES FROM INDIAN CREEK RESERVOIR
October 6, 1969
(Percent Occurrence of Organisms by Rock Scrubbing)

Organism	Station 8
Diptera (flies)	
Chironomidae (true midges)	
Orthocladiinae	
Cricotopus sp.	13.2
Trichocladius sp.	1.5
Chironominae	
Glyptotendipes sp.	85.1
Gastropoda (snails)	
Physidae (pouch snails)	
Physa sp.	.2
Total No. of Organisms Obtained	1,052

Stream

The results from Indian Creek, presented in the Appendix and summarized in Table 6, show a species diversity very low for a stream environment. Dominance by midges, absence of stoneflies and caddisflies, and the presence of only the pollution tolerant mayfly nymph *Siphlonurus* (5,6,7), indicates enriched and eutrophic conditions. The Hemiptera and Coleoptera obtained have air breathing adaptations, and therefore do not reflect water quality insofar as dissolved oxygen is concerned. Field observations revealed that the stream supported a heavy growth of algae, and in general gave the appearance of a nutrient rich stream.

TABLE 6. BENTHIC INVERTEBRATES FROM INDIAN CREEK RESERVOIR
October 8, 1969
(Percent Occurrence of Organisms by Rock Scrubbing
and Mud Sieving)

Organism	Station 9
Ephemeroptera (mayflies)	
Siphlonuridae	
Siphlonurus sp.	2.1
Hemiptera (true bugs)	
Corixidae	
Sigara sp.	.2
Callicorixa sp.	.4
Notonectidae	
Notonecta sp.	.2
Coleoptera (beetles)	
Dytiscidae (predaceous diving beetles)	
Agabus sp.	.1
Laccodytes sp.	.1
Diptera (flies)	
Chironomidae (true midges)	
Orthocladiinae	
Cricotopus sp.	29.0
Nanocladius sp.	60.7
Chironominae	
Microtendipes sp.	5.1
Glyptotendipes sp.	2.1
Total No. of Organisms Obtained 1,143	

IV. CONCLUSIONS

1. Bottom sediments in Indian Creek Reservoir, supported a moderately high concentration of benthic invertebrates (averaging 464/sq ft), but with a very low species diversity. Only five different kinds were obtained, all of which belonged to the family Chironomidae (midges). Of the 1,969 midges acquired from 17 Ekman Dredges, 98% belonged to the low dissolved oxygen tolerant genera *Chironomus* (*Chironomus*), *Procladius* and *Glyptotendipes*. This low species diversity concurrent with overwhelming dominance of forms tolerant of poorly oxygenated waters is symptomatic of eutrophic stratified lakes low in dissolved oxygen within the hypolimnion.

2. The benthic invertebrates of Indian Creek, downstream of the reservoir, exhibited a very low species diversity and a community structure symptomatic of low dissolved oxygen conditions. Of the 1,143 organisms obtained, 97% were midge larvae, a dominance more normally associated with a nutrient rich pond than in a flowing stream.

APPENDIX A

BIOLOGY OF LAKE MIDGES

Chironomids (midges, or sometimes called gnats), are a group of nonbiting, winged insects that require water for their larval and pupal development. The midge larvae are a common inhabitant of streams, lakes and ponds, and occur in a wide variety of habitats and under varying water quality conditions. Different species of midge larvae vary in their sensitivity to polluted conditions, ranging from intolerant to highly tolerant. Their life cycle includes one or more generations per year, depending upon the species and the temperature of their aquatic environment. Most are herbivorous, feeding on algae, aquatic plants, or detritus; but some are predaceous, feeding chiefly on other midge larvae. All are heavily preyed upon by fish, birds, and other animals.

Chironomus (*Chironomus*) sp.

This midge larvae is commonly found in the mud sediments of eutrophic lakes and rivers (8). They are filter feeders, subsisting on phytoplankton and organic detritus (8). From one to five generations may be produced a year, depending upon the species and water temperature (9). The larvae in most cases are blood-red, owing to the presence of a respiratory pigment similar to haemoglobin (9). In addition to its four anal gills, the larvae have two pairs of long ventral gills on the 11th body segment, which further increases its ability to survive under low oxygen conditions (Figure 3). These midge larvae have been reported as nuisance organisms in sewage ponds, and are considered an indication of serious pollution when occurring as a dominant form in dense populations (10).

Procladius sp.

This midge larvae is a common inhabitant of permanent ponds, lakes and streams (8). They are predaceous, feeding primarily on other midge larvae (8), and have been reported as typically pollution tolerant (11). All the Procladius larvae obtained from Indian Creek Reservoir contained a distinctive red pigment that was localized in the anal region and extended throughout the four anal gills (Figure 4). While not previously reported in the literature, it is possible that this species contains a respiratory pigment similar to *Chironomus* (*Chironomus*), thereby increasing its ability to exist in oxygen deficient waters.

Glyptotendipes sp.

The larvae are plankton feeders (8) consuming algal filaments, spores, diatoms and plant tissues (12). The larvae are blood-red due to a respiratory pigment. They have one pair of short gills on the 11th body segment (Figure 5). These adaptations enable the larvae to live in oxygen deficient waters. *Glyptotendipes paripes* have been reported as a nuisance organism in sewage ponds (10). The larvae obtained from bottom sediments of Indian Creek Reservoir generally had longer gill development than those obtained from rocks along the shoreline shallows.

Chironomus (*Cryptochironomus*) sp.

The larvae of most species are predaceous, feeding on oligochaetes and other midge larvae (8).

Tanytarsus sp.

The larvae are plankton feeders (8).

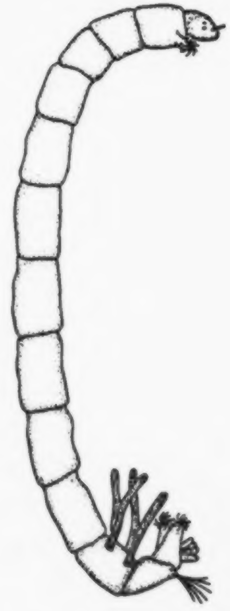
FIGURE 3.^{a}

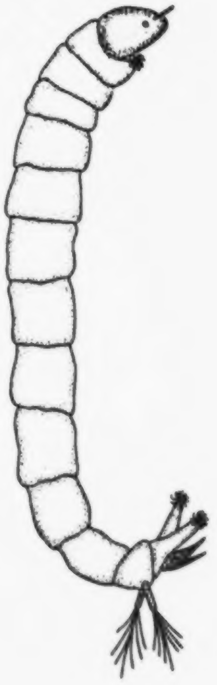
FIGURE 4.^{b}

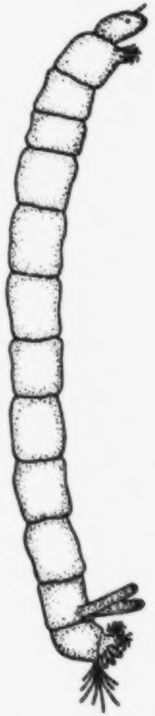
FIGURE 5.^{c}

a. MIDGE LARVAE *Chironomus* (*Chironomus*) sp. (6x)
b. " " *Procladius* sp. (11x)
c. " " *Glyptotendipes* sp. (7x)

APPENDIX B

DATA

STATION 1

Organism	Sample			Total	Mean
	a	b	c		
Cladocera					
Ephippia*	2168	1960	2360	6488	2163
Chironomidae					
Tanypodinae					
Procladius sp.	35	17	33	85	28
Chironominae					
Chironomus (*Chironomus*) sp.	55	47	119	221	74
Glyptotendipes sp.	-	-	2	2	.7
Total Organisms	90	64	154	308	103
Sample Volume (liters)	.6	.6	.6	1.8	.6

STATION 2

Organism	Sample			Total	Mean
	a	b	c		
Cladocera					
Ephippia*	2560	2440	2280	7280	2427
Chironomidae					
Tanypodinae					
Procladius sp.	80	60	56	196	65
Chironominae					
Chironomus (*Chironomus*) sp.	73	78	88	239	80
Glyptotendipes sp.	2	3	2	7	2
Total Organisms	155	141	146	442	147
Sample Volume (liters)	1.2	1.2	1.2	3.6	1.2

STATION 3

Organism	Sample			Total	Mean
	a	b	c		
Cladocera					
Ephippia*	2208	3160	1760	7128	2376
Chironomidae					
Tanypodinae					
Procladius sp.	40	80	60	180	60
Chironominae					
Chironomus (*Chironomus*) sp.	30	111	74	215	72
Glyptotendipes sp.	-	1	-	1	.3
Tanytarsus sp.	1	-	-	1	.3
Total Organisms	71	192	134	397	132
Sample Volume (liters)	.5	.9	.7	2.1	.7

*Ephippia not included in totals.

STATION 4

Organism	Sample a	Sample b	Sample c	Total	Mean
Cladocera					
Ephippia*	1840	2520	1632	5992	1997
Chironomidae					
Tanypodinae					
Procladius sp.	50	41	32	123	41
Chironominae					
Chironomus (*Chironomus*) sp.	121	141	91	353	117
Glyptotendipes sp.	1	2	4	7	2
Tanytarsus sp.	1	1	1	3	1
Total Organisms	173	185	128	486	162
Sample Volume (liters)	1.2	1.0	.6	2.8	.9

STATION 5

Organism	Sample a	Sample b	Sample c	Total	Mean
Cladocera					
Ephippia*	480	400	2520	3400	1133
Chironomidae					
Tanypodinae					
Procladius sp.	17	13	35	65	22
Chironominae					
Chironomus (*Chironomus*) sp.	34	8	69	111	37
Glyptotendipes sp.	1	8	2	11	4
Tanytarsus sp.	-	3	10	13	4
Unidentified pupae	-	-	1	1	.3
Total Organisms	52	32	117	201	67
Sample Volume (liters)	.6	.9	.6	2.1	.7

STATION 6

Organism	Sample a
Cladocera	
Ephippia*	616
Chironomidae	
Tanypodinae	
Procladius sp.	45
Chironominae	
Chironomus (*Chironomus*) sp.	20
Glyptotendipes sp.	5
Tanytarsus sp.	20
Unidentified pupae	1
Total Organisms	91
Sample Volume (liters)	.6

*Ephippia not included in totals.

STATION 7

Organism	Sample a
Cladocera	
Ephippia*	2640
Chironomidae	
Tanypodinae	
Procladius sp.	26
Chironominae	
Chironomus (*Chironomus*) sp.	7
Chironomus (*Cryptochironomus*) sp.	1
Glyptotendipes sp.	5
Tanytarsus sp.	5
Total Organisms	44
Sample Volume (Liters)	1.2

STATION 8

Organism	Sample a
Chironomidae (midges)	
Orthocladiinae	
Cricotopus sp.	139
Trichocladius sp.	16
Chironominae	
Glyptotendipes sp.	895
Physidae (snails)	
Physa sp.	2
Total Organisms	1052

STATION 9

Organism	Sample a
Ephemeroptera (mayflies)	
Siphlonuridae	
Siphlonurus sp.	25
Hemiptera (true bugs)	
Corixidae (water boatmen)	
Sigara sp.	2
Callicorixa sp.	4
Notonectidae (backswimmers)	
Notonecta sp.	2
Coleoptera (beetles)	
Dytiscidae (predaceous diving beetles)	
Agabus sp.	1
Laccodytes sp.	1
Diptera (flies)	
Chironomidae	
Orthocladiinae	
Cricotopus sp.	332
Nanocladius sp.	694
Chironominae	
Microtendipes sp.	58
Glyptotendipes sp.	24
Total Organisms	1143

*Ephippia not included in totals

LIST OF ALL ORGANISMS OBTAINED

Organism	Stations			Total
	1 - 7	8	9	
Cladocera (water fleas)				
Ephippia (winter eggs)	13352	-	-	13352
Ephemeroptera (mayflies)				
Siphlonuridae				
Siphlonurus sp.	-	-	25	25
Hemiptera (true bugs)				
Corixidae (water boatmen)				
Sigara sp.	-	-	2	2
Callicorixa sp.	-	-	4	4
Notenectidae (backswimmers)				
Notonecta sp.	-	-	2	2
Coleoptera (beetles)				
Dytiscidae (predaceous diving beetles)				
Agabus sp.	-	-	1	1
Laccodytes sp.	-	-	1	1
Diptera (flies)				
Chironomidae (true midges)				
Orthocladiinae				
Cricotopus sp.	-	139	332	471
Nanocladius sp.	-	-	694	694
Trichocladius sp.	-	16	-	16
Tanypodinae				
Procladius sp.	720	-	-	720
Chironominae				
Chironomus (*Chironomus*) sp.	1166	-	-	1166
Chironomus (*Cryptochironomus*) sp.	1	-	-	1
Glyptotendipes sp.	38	895	24	957
Tanytarsus sp.	42	-	-	42
Microtendipes sp.	-	-	58	58
Unidentified pupae	2	-	-	2
Gastropoda (snails)				
Physidae				
Physa sp.	-	2	-	2
Total Organisms	1969	1052	1143	4164

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APPENDIX G

TABLE XXXIII

ANALYTICAL PROCEDURES

1. pH and alkalinity were determined by Standard Methods [9].

   Total alkalinity expressed as mg/ℓ $CaCO_3$ was determined by potentiometric titration. The pH recorded was the initial pH of the water before the acid was added in the titration.

2. Iron.

   The bathophenanthroline method outlined by Strickland and Parsons [10] was used for determination of total soluble iron, including ferrous and ferric iron, and complex ferric and colloidal ferrous forms.

3. BOD [9].

   BOD determinations were performed on unfiltered samples. Lake Tahoe water was used to dilute waste water samples when necessary. Generally no dilution for stream water was required.

4. COD [9].

   COD determinations were performed on unfiltered samples. Because both dilute water samples and waste water were analyzed, oxidation was accomplished by using 0.25 N, 0.05 N, and 0.025 N $K_2Cr_2O_7$.

5. NO_3 [10].

   NO_3 in water was reduced to NO_2 by passing the sample through a column of cadmium filings. The NO_2 was then determined.

6. NO_2 [10].

   NO_2 was determined by colorimetric reaction using sulphanilamide and naphthylethylenediamine solution.

7. NH_3 [9].

   NH_3 was distilled into a boric acid solution and then nesslerized. Equipment used for the analyses was divided into two sets, one for distillation of samples with relatively high concentrations of ammonia and the other for samples with low levels such as lake and creek samples.

8. Soluble Organic Nitrogen [9,10].

   The sample remaining after NH_3 distillation (usually about 24 mℓ) was digested with a sulfuric acid-selenium dioxide mixture. When the digestion was complete, the residue was diluted with NH_3-free water, made alkaline, and distilled for the NH_3 as reported above.

9. Inorganic Phosphorus (Reactive) [10].

   The sample was mixed with a reagent containing sulfuric acid, ammonium molybdate, and antimony potassium tartrate, adding afterwards ascorbic acid dissolved in ethyl alcohol. The blue color was then read directly from a Beckman spectrophotometer in a 1-cm or 5-cm cell. (The modification used was reported by Richard Armstrong, Institute of Ecology, University of California, Davis.)

10. Total Inorganic Phosphorus [9].

    Total inorganic phosphorus was determined after hydrolysis with a strong solution of sulfuric and nitric acids. A 100 mℓ sample with the acid solution was autoclaved, cooled and then made alkaline. The inorganic phosphorus was then determined as described above.

11. Chlorides [9].

    Chlorides were titrated with mercuric nitrate.

12. Calcium [9].

    Calcium determinations were made by titration with EDTA (ethylenediaminetetraacetic acid).

13. Conductivity [9].

    Specific conductance (μ mho/cm) measurements were done with a conductivity bridge, Model RC 16B2, made by Industrial Instruments, Inc.

14. Inorganic Carbon [24].

    Calculated from alkalinity measurements for initial conditions of temperature and pH.

TABLE XXXIV

COULTER COUNTER VERSUS HAND COUNT COMPARISON

Sample Type	Date of Sample	Test Organism	Counting Technique	
			Coulter Counter cell no./mm^3	Hand Count cell no./mm^3
MLT[a]	7-1-69	S. gracile[f]	42	61
SLT[b]	7-1-69	S. gracile	42	55
Ward Creek[c]	7-1-69	S. gracile	46	51
Incline Creek[d]	7-1-69	S. gracile	46	54
Truckee-Trout Creek[e]	7-1-69	S. gracile	47	59
MLT	7-1-69	S. cap.[g]	55	65
SLT	7-1-69	S. cap.	57	62
Ward Creek	7-1-69	S. cap.	51	67
Incline Creek	7-1-69	S. cap.	59	68
Truckee-Trout Creek	7-1-69	S. cap.	62	61

[a] Mid-Lake Tahoe.

[b] Shore-Lake Tahoe.

[c] Ward Creek – Upstream side of bridge on Highway 89.

[d] Incline Creek – Approximately 150 ft upstream from bridge on Lakeshore Boulevard (old Highway 28).

[e] Truckee-Trout Creek – Downstream from the confluence of the Upper Truckee River and Trout Creek across from the Marina of the Tahoe Keys development.

[f] Selenastrum gracile.

[g] Selenastrum capricornutum.

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